SURFACE ENVIRONMENT & MINING
SEAM
USDA FOREST SERVICE PROGRAM

USER GUIDE to SOILS

Mining and Reclamation in the West

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INTERMOUNTAIN FOREST AND RANGE
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RESEARCH SUMMARY

The soils scientist working on mined land must be aware of potential impacts of mining, as well as reclamation techniques available to him. This guide covers major points of concern to the soils scientist involved in planning for reclamation of mined land including: exploration and baseline data; soils and overburden analysis and sampling techniques; selecting storage areas; materials handling; spoils analysis; treating spoils problems; spoils surfacing; and monitoring and retreatment.

Information is presented in a question/rule/discussion format, and includes supporting graphic material, notes on additional sources of information, a glossary, and an index.

ACKNOWLEDGMENTS

The contents of this guide are based on presentations and discussions during the Surface Environment and Mining (SEAM) sponsored Soils Workshop, March 7-9, 1979, Denver, Colorado. Credit is due all attendees and presenters for their input. Those who attended are listed in appendix B. In addition, major contributors are listed under chapter titles as appropriate.

A special note of thanks is extended to Earl F. Aldon, Ardell J. Bjugstad, Paul E. Packer, and Robert Partido, members of the cadre which planned the workshop. The workshop program coordinator was Edwin R. Browning (SEAM) and the technical adviser was Grant Davis (SEAM).

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INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
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INTRODUCTION

MINERAL AND NONMINERAL RESOURCES

An adequate, reliable supply of minerals is essential to the economy and security of the United States, since minerals provide the physical basis for almost all activities of U.S. citizens. While imports can satisfy an important part of the country's minerals demand, they make the U.S. vulnerable to the economic and political decisions of foreign countries. Thus, the mineral deposits within the U.S. are a most important source of this nation's supply.

A substantial portion of the domestic minerals supply presently comes from lands managed by the Federal Government. Federal lands are known to contain a majority of the metallic minerals, as well as major resources of coal, oil shale, geothermal steam, uranium, and oil and gas. These same Federal lands, however, also contain valuable nonmineral resources, including timber, forage, water, wildlife, scenic landforms, and wilderness. The Government's holdings of such resources are now among the most significant in the world.

While it is clearly in the national interest to provide for the identification and production of the mineral resources on Federal land, it is also necessary to provide for a sustained high-level output of the various renewable resources on that land. Thus, the demand for mineral development must be balanced against the demand for renewable resources and the land-management agency's responsibility to reasonably protect the environment affected by mineral-related operations.

MINERALS IN THE LAND-MANAGEMENT PLANNING PROCESS

The Forest Service, as one of the agencies responsible for Federal land management, has a relatively sophisticated planning program for the management of nonmineral resources on land under its jurisdiction. Historically, however, the Forest Service's land-management and planning systems have treated minerals as a distinct category outside of the mainstream of the land-management planning process. There are two basic reasons for this separation:

1. The mining and mineral leasing laws have tended to make mineral activity the preferred use on any Federal land open to such activity. The thinking has been that on lands open to mineral activity, mineral development will generally override the designated primary nonmineral uses.

2. Planning for use of the mineral and nonmineral resources is complicated considerably by the difficulties of identifying and estimating the value of mineral resources. Mineral resources can be found only through costly and risky exploration. Therefore, land-management planning has tended to concentrate, at least until a mineral discovery is made, on the surface resource potential of the land.

The long-standing premise that mineral activity is always the most valuable use of a tract of land is increasingly being challenged. Many mineral deposits being discovered today are of lower grade, located at greater depths, and are therefore more expensive to find and mine than the high-grade surface deposits formerly developed. Another significant factor is that nonmineral surface resources are now also considered to be scarce, and their value has increased accordingly.

Hence, when all the mineral and nonmineral values are weighed for a particular proposal at a specific location, the value of the mineral resources may be outweighed by the value of the nonmineral resources. The process of weighing values usually occurs in an Environmental Assessment required by the National Environmental Policy Act of 1969 (NEPA) (P.L. 91-190) and is basic to determining the proper mix of uses for any given land area.

Given this situation of mineral and nonmineral values on the same tract of Federal land, decisions as to the proper use of a particular tract of land will always involve balancing the values of mineral and nonmineral resources. If this balancing is to be done in a reasonable manner, adequate information and analysis of all values are needed.

BACKGROUND: THE FORMATION AND MISSION OF SEAM

Realizing the complexity of such decisions, in 1973, the Forest Service chartered the Surface Environment and Mining program (SEAM) to coordinate research, development, and application related to land impacts resulting from minerals exploration and development in the West. From 1973 to 1979, SEAM sponsored more than 150 research and development projects. Together, the projects have greatly added to the body of knowledge surrounding the management of land in mineralized areas. (For purposes of this discussion, mineralized areas are defined as those areas that have some potential for mining.)

To get this knowledge to the specialists in the field in a form they could readily use, SEAM brought together researchers and users from industry, Federal agencies, and the academic community to share their practical knowledge and study results in a series of workshops. The information presented at these workshops is organized into five user guides. Each guide focuses on a specific discipline involved in managing surface resources that may be affected by mineral activities and is written for specialists in these disciplines. The guides will also be of use to land managers, land planners, and other specialists, since many activities related to minerals-area management demand that a variety of skills be applied to achieve an integrated approach.

In addition to the User Guide to Soils, guides have been written for vegetation, hydrology, engineering, and sociology and economics. Cross-referencing among these guides is provided in the index. A handbook for minerals specialists has also been written. A handbook for land managers will provide a general overview of administrative considerations surrounding mineral commodities commonly explored for and developed on national forest lands administered by the Forest Service. Concurrent with the development of the SEAM user guides, a USDA handbook of visual management related to mining and reclamation, entitled "Mining," is in press as volume 2 of the National Forest Landscape Management Series. A guide for the wildlife specialty is also planned. All guides will be updated periodically to keep them current with research findings.

The purpose of the guides is to help specialists more clearly understand their role in mineral exploration and development activities by outlining some of the major considerations they must address to insure that such activities integrate with land-management plans; that impacts are mitigated to a reasonable degree; and that reclamation meets state-of-the-art performance standards. Perhaps by using these guides as a common starting point, those involved in minerals management can more easily work together toward achieving these common goals: (1) appropriate consideration of minerals values in land-management planning; (2) protection of surface resources during mining activities; and (3) reclamation of surface-mined land to a productive use.

HOW TO USE THIS GUIDE

The chapters of this guide cover topics that concern the soils scientist during both land-management planning and any subsequent minerals activity. Within each chapter, major topics will be addressed in this way:

- Considerations: These are the questions the soils scientist should ask about each topic.
- Rules: These general statements answer the questions and direct the soils scientist toward the type of site-specific information the land manager may need to make decisions. Rules are set in italic type.
- Discussions: The discussions explain the reasoning behind the rules and in some cases give specific examples of how the rules are applied.
- Exceptions: Exceptions to various statements are given where applicable.
- Additional Information: Here the reader will

find basic references to further information on the topic discussed.

The aim of this format is to help define the role of the soils scientist in minerals management. The guide is not intended to be a "cookbook" on rehabilitation techniques. Rather, it is intended to set up a logical thought process based on a question/answer approach. Such an approach allows for flexibility, eliminates unnecessary data gathering, helps simplify technical decisionmaking, and allows for a systematic documentation of the decisionmaking process. We hope that this organization of material will make the guides equally useful to users in industry, Federal and State agencies, and the academic community.

The role of the Forest Service staff is illustrated in table 1, "Stages of Mineral Exploration and Development Activities," and table 2, "Roles of Forest Service Specialists in Minerals Activities," which follow this introduction. As you will note, the Forest Service soils scientist will advise, review, and monitor. For example, although materials handling takes place during mining and reclamation, the soils scientist will review these plans when the operating plan is submitted prior to development and, if necessary, suggest revisions to the plan to improve reclamation potentials. Then, during mining and reclamation, the Forest Service specialist will monitor these activities according to the approved operating plan. In this way, the effects of the development will be managed in a proactive, rather than reactive mode. In other words, rather than reacting to crises, the soils scientist will be part of the forest's interdisciplinary (ID) team from the time land-management planning begins. Then, if and when mineral activities occur, the team will have foreseen potential problems and will have determined general rehabilitation objectives in advance.

Both land-management planning, in its broader application, and site-specific operational planning for mineral activities on National Forest System lands require the full range of interdisciplinary efforts so that information on both the mineral and nonmineral values can be presented to the decisionmaker in an integrated manner. The interdisciplinary approach to planning is uniquely suited to giving the best available assessment of the spectrum of opportunities and problems of managing surface resources that may be affected by mineral-related operations and the requirements needed for reasonable protection of nonmineral resources. Soils, vegetation, hydrology, topography, geology, wildlife, climate, and social and economic information are some of the factors that must be considered by the ID team.

Land management and planning must always proceed on the basis of existing information. In the case of mineral resources, this will almost always be difficult because the mineral resources are hidden beneath the surface, and information is provided in increments as exploration proceeds. One of the principal goals of Federal land management, therefore, should be to improve such management by obtaining better mineral-resource information and integrating it into the decisionmaking processes.

When using this guide, the reader should keep in mind that, for the most part, the information is concerned with scientific considerations. While other factors, particularly cost and legal constraints, are a crucial part of the planning process, discussion of these aspects is limited here.

One final note: Successful rehabilitation is as much an art as a science. To clarify specific points or to keep up with new developments, readers are urged to contact the researchers who contributed to this guide or their regional reclamation specialists.

Additional Information:

For more information on the mining process, refer to "Anatomy of a Mine," USDA For. Serv. Gen. Tech. Rep. INT-35. 1977. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Table 1. — *Stages of mineral exploration and development activities*[1]

Prospecting	Exploration	Feasibility studies/operating plan
A. Administrative Action No administrative action required; however, some evidence of mineralization or a hunch	A. Administrative Action Permit/Lease Notice of intent from miner (for certain commodities, may also serve as operating plan if there is minimal surface disturbance) Exploration license EA may be necessary See Handbook for Land Managers (in press) for variation within commodities	A. Administrative Action Submission of necessary permits (EA, EIS, etc.) and operating plan—see Handbook for Land Managers (in press) for variation within commodities
B. Activities Literature search Geological inference Evaluation of existing data Research on rights to land/minerals	B. Activities More intensive literature search Access road construction On-site testing and evaluation of data—geological, geochemical, geophysical, drilling, sampling, shaft sinking Seismic activity Acquiring land/mineral rights Rehabilitation of exploration impacts Environmental and socioeconomic studies	B. Activities Feasibility studies Grade and size of deposit Cost of mining and rehabilitation Market Fiscal Technical studies—mine design Environmental and socioeconomic studies (if not done during exploration) Decision to proceed with development Preparation of operating plan including rehabilitation program and end use Ordering of equipment
C. Environmental Impacts Minimal, if any	C. Environmental Impacts Roads Drill holes Drill pads Dozer holes Exploration camps	C. Environmental Impacts Generally none at this stage
D. Tasks for the Soils Scientist None at this point	D. Tasks for the Soils Scientist Review of plans to reclaim land impacted by exploration Review and assist in soils aspects of environmental studies Review soils inventory progress in the mineralized area; if needed, recommend timely completion or upgrading	D. Tasks for the Soils Scientist Review adequacy of operating plan for: Reclamation Program — soils surveys storage area selection materials handling plans spoils analysis plan spoils surfacing and erosion control Monitoring/retreatment program for soils Soils aspects of end use

[1] The various phases have considerable overlap. The material provided for each phase is illustrative, not complete, and considerable variation is found by commodity. The existence of a forest plan is assumed. Tasks (D) are primarily input from a land-management agency's soils scientist. For purposes of discussion, the terms reclamation and rehabilitation are used interchangeably, and mining includes oil and gas activities.

Development[2]	Mining/reclamation	Postmining
A. Administrative Action Approval of necessary operating plan	A. Administrative Action No administrative action required. Mining overlaps with development and reclamation overlaps with mining; reclamation of previously mined areas occurs concurrently with new mining as stipulated in operating plan Any changes in operating plan	A. Administrative Action Release of reclamation bond
B. Activities Securing of financing More extensive testing and definition of the mineral Construction of transportation routes and utilities Construction of mine and processing plant (facilities, water supply, etc.) Construction of waste deposits Continued evaluation of data Change mining plan if necessary	B. Activities Extraction of mineral Processing of mineral Depositing wastes Operation of transportation systems Rehabilitation Monitoring for any changes in biological and physical environment Amend mining and rehabilitation plan if necessary	B. Activities Surface owner manages land after bond release Monitoring for any changes in biological and physical environment Management and maintenance for end-use objective
C. Environmental Impacts Mine Processing plant Waste dumps Transportation and access routes Utilities Increased population resulting from construction	C. Environmental Impacts Impacts directly related to operational aspects of mining; impacts are strongly affected by commodity mined and type of operation	C. Environmental Impacts Directly related to management and maintenance activities
D. Tasks for the Soils Scientist Monitor impacts on soils Monitor soils related activities for conformance to operating plan. Advise on plan revisions when necessary	D. Tasks for the Soils Scientist Monitor soils impacts and activities for conformance to operating plan. Advise on plan revisions when necessary Advise from a soils standpoint on release of reclamation bond	D. Tasks for the Soils Scientist Monitor any continued impacts on soils Manage soils for end-use objective

[2] Development is herein defined as the phase which begins after the right to mine has been established.

Table 2.—*Roles of Forest Service specialists in minerals activities*

	Prospecting	Exploration	Feasibility studies/operating plan
Vegetation specialist	None at this point	Review of plans to reclaim land impacted by exploration Review and assist in vegetation aspects of environmental studies	Review adequacy of operating plan for: Reclamation program — species selection plant materials site preparation planting methods cultural treatments Monitoring/retreatment program for vegetation Vegetation aspects of end use
Soils scientist	None at this point	Review of plans to reclaim land impacted by exploration Review and assist in soils aspects of environmental studies Review soils inventory progress in the the mineralized areas; if needed, recommend timely completion or upgrading	Review adequacy of operating plan for: Reclamation Program— soils surveys storage area selection materials handling plans spoils analysis plan spoils treatments spoils surfacing and erosion control Monitoring/retreatment program for soils Soils aspects of end use
Hydrologist	Establish baseline water-quality monitoring as needed according to plan	Review of plans to reclaim land impacted by exploration Review and assist in hydrologic aspects of environmental studies	Review adequacy of operating plan for: Hydrologic considerations— surface water subsurface water snow management roads impoundments mine drainage Hydrologic aspects of end use
Engineer	None at this point	Review of plans to reclaim land impacted by exploration Review and assist in engineering aspects of environmental studies	Review adequacy of operating plan for: Engineering considerations— air pollution transportation facilities surface-mine facilities mine-waste disposal embankments tailings dams and impoundments subsidence Engineering aspects of end use
Economist	Monitor factors which affect supply and demand for minerals Make forecasts of supply and demand Predict probability	Analyze costs and benefits of alternative exploration methods Participate with the sociologist in identification of existing and emerging issues	Provide expertise in environmental analysis process: issue identification decision criteria cost/benefit analysis of alternatives tradeoff and opportunity-cost evaluations Analyze effects of development on: demand for surface resources human behavioral patterns community economics
Sociologist	Identify the basic social/cultural descriptors of the affected communities Note current trends	Assist in structuring public involvement plan for appropriate: issue identification issue analysis mitigation action Identify critical trigger points from a social perspective	Provide expertise in environmental analysis process: decision criteria issue identification Analyze effects of development on the cultural and political community Consider effects of alternative plans on social well-being

Development	Mining/reclamation	Postmining
Monitor vegetation impacts and activities for conformance to operating plan. Advise on plan revisions when necessary	Monitor vegetation impacts and activities for conformance to operating plan. Advise on plan revisions when necessary Advise from a vegetation standpoint on release of reclamation bond	Monitor any continued impacts on vegetation Manage vegetation for end-use objective
Monitor impacts on soils Monitor soils-related activites for conformance to operating plan. Advise on plan revisions when necessary	Monitor soils impacts and activities for conformance to operating plan. Advise on plan revisions when necessary Advise from a soils standpoint on release of reclamation bond	Monitor any continued impacts on soils Manage soils for end-use objective
Monitor impacts on hydrology	Monitor impacts on hydrology and hydrologic aspects of rehabilitation program Have hydrologic input into release of reclamation bond	Monitor any continued impacts on hydrology Manage hydrology for end-use objective
Monitor engineering-related activities for conformance to operating plan Advise on plan revisions when necessary	Advise from an engineering standpoint on release of reclamation bond	Monitor any continued impacts from engineered structures Manage structures for end-use objective
Record costs Monitor economic changes	Record costs Monitor economic changes	Monitor to determine accuracy of predictions for future use
Monitor Record changes Identify areas of individual or group stress relating to mineral activity and make recommendations to mitigate effects	Monitor Record changes	Monitor and record critical changes to establish new baseline situation

Chapter 1
EXPLORATION AND BASELINE DATA

Chapter Organizer: Grant Davis

Major Contributor: Grant Davis

Mineral exploration is the process of identifying and investigating "targets" in order to discover an economic mineral deposit. Exploration begins with regional studies that create little or no disturbance or occupation of the land. In addition to compiling existing geologic and photogeologic information, exploration also involves geologic mapping and geochemical surveys. By the time a regional study has defined specific target areas, only a small portion of the lands originally considered is selected for more intensive study and exploratory work. At this stage, some land disturbance—drilling, for example—may occur.

Should a mineral deposit be found, the area of land involved is subject to more intensive exploratory work in a tighter pattern and is accompanied by more surface disturbance. If the exploratory work locates an ore body, development and mining are confined to an even more localized land area. Thus, a mining company's decision to explore an area for mineral deposits will require the land-management agency's personnel to become involved in a more intense analysis of the site than would normally occur during land-management planning.

What input is needed from the soils scientist during exploration?

During exploration, the activities of the soils scientist will increase in intensity in direct proportion to the types and magnitude of surface disturbances caused by the various phases of exploration. And, if an exploration permit is needed, the soils scientist should be among the team reviewing exploration plans.

Discussion:

During the initial and intermediate stages of exploration, when seismic activity, some core drilling, and pioneer road building may occur, the soils scientist can generally rely on existing soils survey data or extrapolate soils data from areas with similar environments in order to advise on the potential for rehabilitation of these disturbances. If, however, access to the site will cause significant surface impact, an Order 3 soils survey may be needed. Based on this knowledge, the soils scientist should be prepared to offer information on alternative road sites if the soil at the site selected by the operator is either unstable or so productive that it should not be disturbed. Consult with an engineer on these decisions.

Any pad construction will also require a site-specific study in order to determine how it can be reclaimed. If exploration leads to excavation of waste rock material, the soils scientist should offer his expertise along with the engineer to insure that salvageable soils and the waste materials are stockpiled properly and positioned to best advantage on the rehabilitated spoils pile.

During this time, the soils scientist should also work with the mining operator to gather preliminary information on the geology and overburden of the area. For example, if possible, he should obtain the drill cores or a log of the core drilling activity. If the company is not taking core drills, even chips will be valuable in this preliminary analysis, provided samples collected can be related to depth of drilling.

Obviously, as is the case during land-management planning, this information will remain rather general, but it will provide some indication of potential problems, such as toxicity or erodibility, that may be encountered if the site is mined.

Does the Forest Service have access to a mining company's data?

If a mining company has collected data about a leasable mineral, the company is required to

give the Forest Service certain information about such mineral deposits. A prospecting permit may require the company to supply this information. A coal license absolutely requires this information from a mining company. For locatable minerals, any information collected is considered "privileged," and the company that collected it controls access to it.

Discussion:

Because mining companies have complete control of certain information they collect during exploration, prior data collection by the Forest Service ID team is essential. The Forest Service should have information about every mine site on its land, whether for a leasable or locatable mineral, because, in either case, it will be the responsibility of the Forest Service to insure that surface conditions are not irrevocably harmed during mining. In addition, a close working relationship between the Forest Service and the mining company, developed early in the mining process, can be beneficial to both parties since their combined effort can produce a more thorough data base.

BASELINE DATA AND THE MINING PLAN

Once exploration is complete and the mining company determines that it will mine the site, an Environmental Assessment may be in order and the formal gathering of baseline data to be included in the mining plan begins. Baseline data measure the conditions existing on the site prior to disturbance, help determine reclamation goals, and provide a basis against which reclamation success can be measured. Based on these comparisons, the mining operator may or may not be released from his bond of liability subsequent to mining and reclamation activities.

At this point, more detailed information about the site may be needed to answer specific issues or management concerns identified in the planning process. This information must be scientifically sound and well documented. In addition, ID team members should coordinate their efforts so that the data collected do not overlap.

What is the role of the soils scientist in baseline data collection and approval of the mining plan?

The soils scientist will advise on the type and extent of soils information that will be required from the operator in order to approve the mining plan. He will be specifically concerned with data needed to answer questions related to soils in the Environmental Assessment. The goal: To collect sufficient information in order to predict (1) the characteristics and volume of salvageable soil materials; (2) what type of spoils material will result from mining; and (3) the rehabilitation potential of the site.

Discussion:

The soils scientist should determine what soils information is appropriate to the concerns that need to be answered, what funds are available for collecting the data, and who will collect it. He should require only the level of data needed to answer specific questions for the land manager or to meet legal requirements. This level of data usually requires on-site studies.

Soil types must be indicated in the mining plan, which will require at least an Order 3 soils survey for the general area and probably an Order 2 or 1 survey on areas planned to be disturbed. At this point, productivity ratings will be developed by soil correlation techniques based upon the documented history and management experience with the same or similar types of soils series as the one under study. Greenhouse studies and lab analyses will generally be required in order to identify toxic or infertile soils materials and to predict weathering characteristics, erosion potentials, and moisture factors. The core samples collected during advanced exploration work can be used for this analysis.

After analysis of these data, the soils scientist should be able to advise the land manager whether to accept, reject, or modify a company's mining plan, based on how the plan addresses soils considerations. The soils scientist may also be responsible for proposing options to the mining plan either alone or as a member of an ID team. The land manager can request a periodic review of the plan during which changes can be made if (1) the mining processes are unreasonably damaging soils resources; or (2) only preliminary baseline data are included in the mining plan.

Additional Information:

Detailed soils and overburden analysis, which

is done only after the company has determined it will mine the site but prior to approval of the mining plan, is discussed in chapter 2.

Who collects baseline soils data?

Either the Forest Service or the mining company may collect the baseline data. Responsibility for data collection will be negotiated between the Forest Service and the mining company in each mining situation after the company has made the decision to mine.

Discussion:

When the mining operation will be on Forest Service land, it is the responsibility of the land manager to determine if the mining plan has an adequate baseline data design, and then if the data are collected according to the plan.

Although it is the responsibility of the Forest Service to insure that baseline data requirements are met by operators on Forest Service land, in certain areas of the country, the Forest Service is considering allowing State agencies to enforce their own State requirements on National Forest System lands because these regulations are at least as stringent as Forest Service or Federal requirements. An example is the State of Wyoming. In these situations, the Forest Service will still approve mining plans and will retain authority over Forest Service lands.

In the case of small mine operators, extensive data collection may be economically unfeasible. To aid these operators, Federal assistance can be applied for through the Small Operators Assistance Program, Office of Surface Mining, U.S. Dept. of the Interior. This program was established by the Surface Mining and Reclamation Act of 1977 (P.L. 95-87, 30 U.S.C., Secs. 1201 etseq.).

Who must gather the soils information for Environmental Assessments if they are required?

If the operation is located on national forest lands, the forest supervisor may be required to provide the information, in which case the soils scientist will probably be involved in data collection.

Discussion:

The Forest Service soils scientist may be actively involved in data collection, or involved only in review of the data, depending on who must supply the data. In either case, the same kind of information is needed.

Should baseline data be computerized?

If a large amount of data will be collected or an Environmental Assessment or Environmental Impact Statement is required, computerizing the data may aid in easy retrieval during mining activity and postmining monitoring.

Discussion:

The decision to computerize the data should be made before or in the early stages of the data collection process. If there is going to be a large baseline requirement and an intense monitoring requirement throughout the mining process, the option to computerize the data should be considered.

What other activities are important considerations during baseline studies?

The soils scientist should urge those doing baseline studies to watch for archaeological resources as the site is examined. The specialist should also encourage establishment of permanent study plots for use throughout the mining, reclamation, and postmining phases.

Discussion:

Although a trained archaeologist will conduct an official paleontological or archaeological survey, all members of the team should aid in locating such objects during field studies.

Study plots will be essential throughout the mining process to determine what reclamation techniques are most successful on the site (fig. 1).

Additional Information:

For more information on baseline studies, refer to:

"A Systems Approach to Ecological Baseline Studies," U.S. Dept. of the Interior, Biological Services Program, Fish and Wildlife Service, FWS/OBS-78/21. March 1978.

"Procedures Recommended for Overburden and Hydrologic Studies on Surface Mines," by James Barrett, Paul Deutsch, Frank G. Etheridge, William T. Franklin, Robert D. Heil, David B. McWhorter, Daniel Youngberg.

Colorado State University and USDA For. Serv., Douglas, Wyo. December 1978.

"Guidelines for Estimating Potential Land Capability and Range Sites as a Part of Reclamation Planning and Alternative Analysis," Thunder Basin National Grasslands, Hayden D. Rounsaville, USDA For. Serv., Medicine Bow National Forest (location). September 1977.

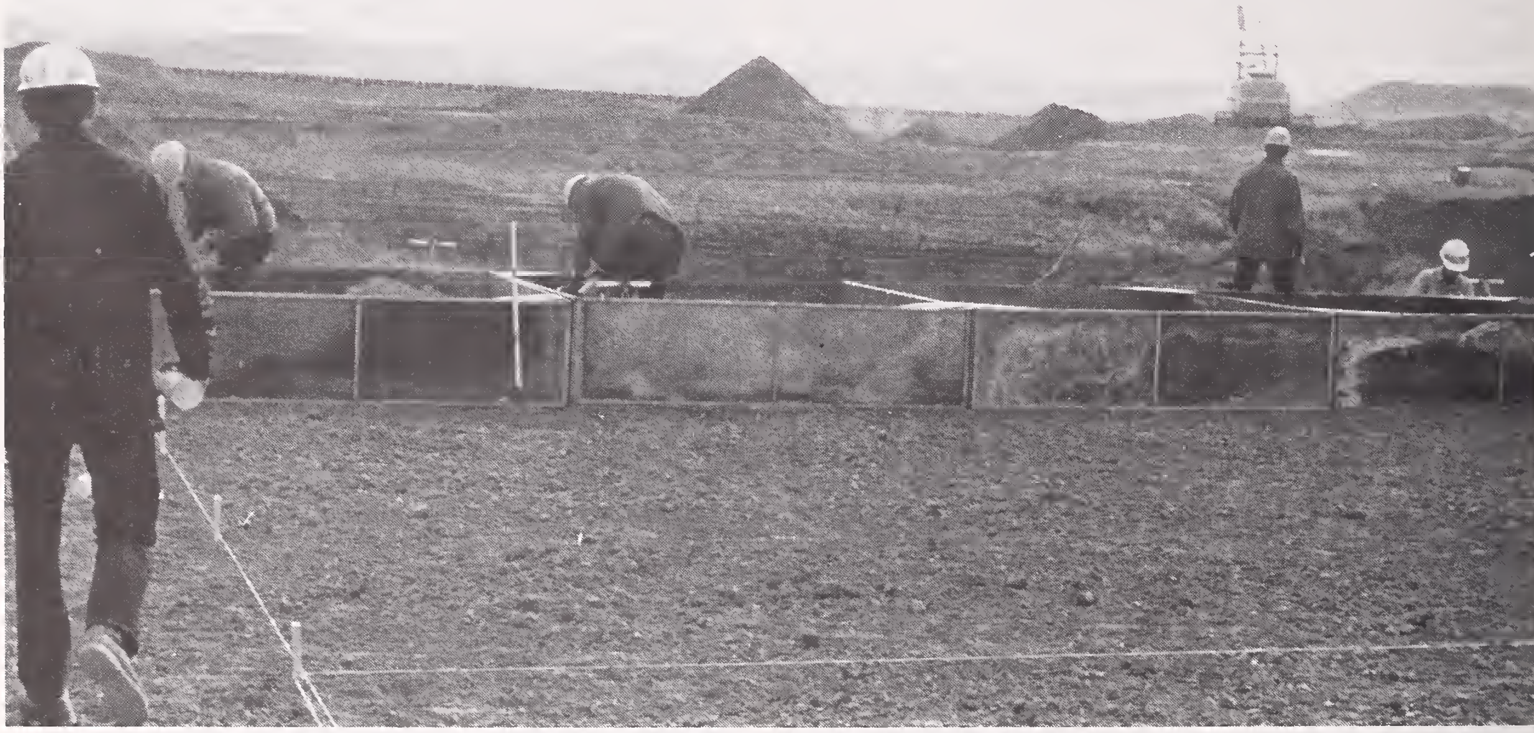

Figure 1. On-site study plots are valuable in testing proposed revegetation techniques.

Chapter 2
SOILS AND OVERBURDEN ANALYSIS AND SAMPLING TECHNIQUES

Chapter Organizer: William A. Berg

Major Contributors: William A. Berg, Stephen D. Merrill, Douglas J. Dollhopf

After a mining company has pinpointed the mineral deposit it plans to mine, a determination must be made on the reclamation potential of the site. The baseline studies discussed in chapter 1 will aid the mine operator and the land manager in making such a determination. Soils and overburden analysis is a special component of these baseline studies, because these tests will identify if and how much topsoil should be stockpiled for placement on the mined spoils. (For purposes of this discussion, overburden includes materials overlying a minable deposit, up to but not including the topsoil. See figure 2.)

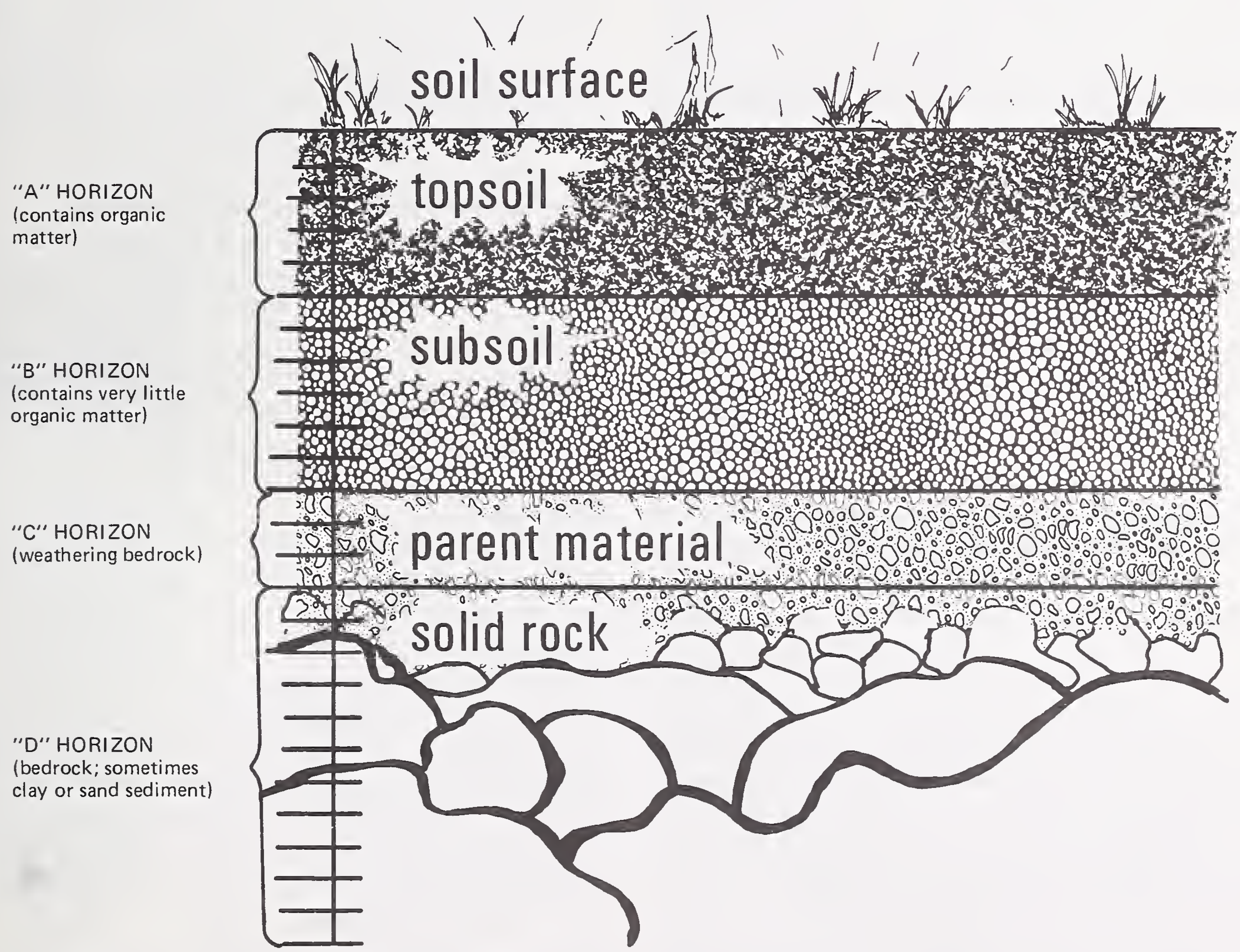

Figure 2. For purposes of discussion in this guide, soils compose the "A" horizon shown in the above profile. •Overburden is the B, C, and D horizons, which overlie the mineral seam. (Utah State University)

Similarly, the analysis will identify zones in the soils or overburden that may adversely affect revegetation efforts when this material is replaced on the site as spoils.

Mining and reclamation plans are drawn up based on this premining analysis. For example, a decision can be made on how much topsoil to save. If feasible, the plan may state how selective handling of certain inhibitory zones will be accomplished—perhaps by burying and capping them—so that the most desirable material for plant growth is left on or near the surface. In addition, certain chemical and physical treatments of the spoils may be planned to ameliorate foreseen problems.

Caution in relying completely on these premining tests is important, however, because the actual spoils may exhibit characteristics different from those predicted during soils and overburden analysis. Thus, spoils analysis after mining and grading must always be done (see chapter 5), and the mining operator should be prepared to alter his rehabilitation plan if the results of spoils analysis indicate previously undetected problems.

Final interpretation of the analyses run during premining sampling must be made by the soils scientist in the field. He chooses the appropriate tests, sends them to the lab if necessary, looks at the results, and correlates these results with what he observes on the site.

This chapter will discuss the analyses recommended to characterize the physical and chemical properties of the soils and overburden; use of analyses to predict productivity and erodibility; analyses specifically recommended to determine if and how much topsoil should be stockpiled for respreading on the spoils; and sampling methods commonly used. Some of these analyses can be done by field observation; others must be performed in a lab. The analyses performed should be appropriate to the specific site, based on the knowledge the soils scientist has gained from soils inventories and other baseline studies. Obviously, not all tests described in this chapter will be necessary on any one site. Also note that this discussion is based on current research, but, in some situations, State or Federal regulations may prescribe the types of soils and overburden analysis that must be performed. In addition, other members of the ID team, for example, the engineer, may need other types of tests. The premining analysis program should be coordinated with these other specialists.

ANALYSES TO CHARACTERIZE SOILS AND OVERBURDEN

How are the appropriate tests selected?

Because more than one test can be used to identify the same characteristic, it is recommended that the most basic tests be done first. Then, if the characteristic under analysis shows up as questionable or a possible problem area, further tests should be run. This step-down approach to soils and overburden analysis will save both time and money.

Discussion:

Tables 3 through 7 indicate various analyses used to characterize soils and overburden. An "S" following certain tests indicates that they should only be used in special situations. Some of these situations are outlined in the following discussion; the soils scientist can also make a determination on the necessity of these tests based on the results of the basic analysis.

How is overburden information obtained?

Overburden information is obtained from soil horizon sampling during soil mapping, from the cores taken from the site during exploratory drilling, or from materials excavated during exploration. Soil horizon sampling is generally confined to the upper 5 ft. If necessary, additional cores may have to be drilled.

Discussion:

A major step in mined-land reclamation is premining overburden analysis. Thus, it is extremely important that the mine operator be aware that any samples taken to evaluate the ore deposit can also be used to determine the properties of the overburden and the overburden's reclamation potential. If core samples are taken during exploration, they should be saved for this analysis. Due to their expense, however, tests should only be run after the mining company has determined it will mine the site, but prior to submitting the operating plan.

What physical characteristics should be identified by field observation?

Physical characteristics important to soils and

overburden analysis include horizon thickness, lithology, coarse fragments, color, texture, structure, consistency, hardness, root distribution, presence of lime, presence of soluble salts, and kinds of vegetation present.

Discussion:

Much of the work involved in field observations of physical characteristics is conducted as part of the soil survey. Table 3 lists the field observations recommended to determine physical characteristics in the soils and overburden. In some cases, a characteristic important to the soil is not applicable to the overburden and vice versa. Some specific notes on the tests listed in table 3 follow:

- Coarse fragments. It has been noted that coarse fragment identification in the soil is often omitted. But if the soil has 70, 60, even 40 percent coarse fragments, lab tests will be interpreted differently and thus these fragments should be noted.
- Hardness. Hardness and accompanying lithology information indicate that the overburden material is, for example, a hard shale or a soft shale.
- Root distribution and vegetation. The soils scientist should work with the vegetation specialist in noting these characteristics.

Additional Information:

Most of the characteristics listed in table 3 can also be found on profile description forms, such as the Soil Conservation Service form SCS-232 or the Forest Service form FS 2500.

What physical characteristics should be identified by lab analysis?

Texture, dispersion, weatherability, water-retention capacity, saturation percentage, and hydraulic conductivity are all lab tests that may be performed to further define the physical characteristics of the soils and overburden.

Discussion:

Table 4 lists the lab tests recommended to characterize the soils and overburden. Some of these tests will be used by the engineer rather than by the soils scientist; however, they are included in the list because sampling can be done at the same time for both types. Other notes on specific tests:

- Texture of the soil (fig. 3 and 4). If the experienced soils scientist can make a determina-

Table 3.—*Field observations of physical characteristics*

Observe	Soil	Overburden
Horizon thickness	Yes	NA[1]
Lithology, including parent material	Yes	Yes
Coarse fragments	Yes	NA
Color	Yes	Yes
Texture	Yes	Yes
Structure	Yes	NA
Consistency	Yes	NA
Hardness	NA	Yes
Root distribution	Yes	NA
$CaCO_3$	Yes	Yes
Soluble salt/crystals	Yes	Yes
Vegetation (species composition and ground-cover characteristics)	Yes	NA

[1]NA: Not applicable.

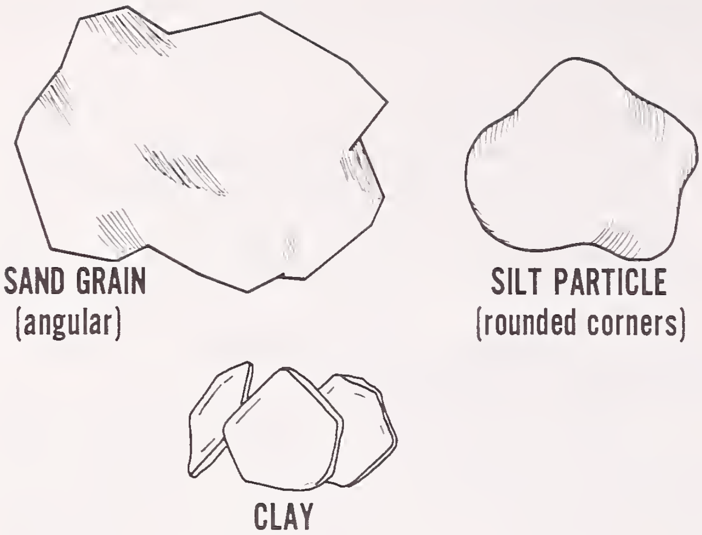

Figure 3. Texture is determined by the proportions of sand, silt, or clay contained in the soils and overburden. (Utah State University)

tion of soil texture in the field, laboratory analysis may not be necessary. When extremes in either clay or sand exist, however, texture tests should be made to obtain more information and to verify field estimates.

• Dispersion. Dispersion is useful to indicate the initial slakability or weathering of spoils material, especially if the material is of a clay type.

• Weatherability. This test should be run on overburden materials if they will become a plant-growth medium after mining. In addition, it is useful to identify exposed rock strata and note how they have weathered, then relate these observations back to weatherability lab tests on the core samples.

• Water-retention capacity (fig. 5). In some cases, if the soils scientist feels he has a good

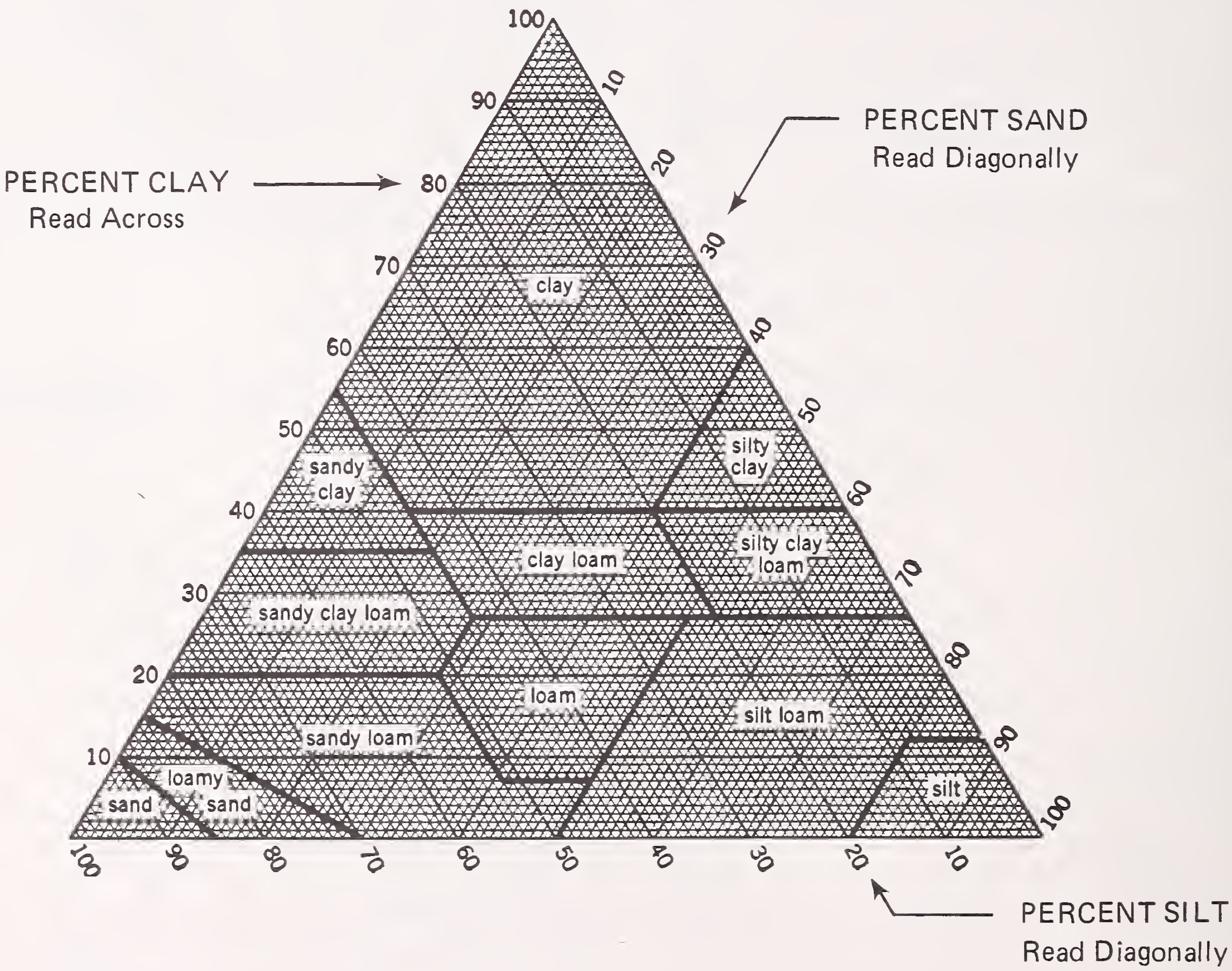

Figure 4. Soil texture triangle. (USDA Soil Conservation Service)

understanding of the soil's texture and organic matter content through field observations, he may be able to adequately estimate water-retention capacity without running this specific test. In arid areas, however, such as the Southwest and Great Basin, water-retention capacity, as expressed by bar or tension values, is considered a critical interpretation. More about this test follows later in this chapter.

- Saturation percentage. Saturation percentage is used as an indicator of sodium problems and thus is needed where high sodium is expected.
- Hydraulic conductivity. This test adds to the soils scientist's knowledge of the kind of soil/moisture relationships that may occur after mining. More about this test follows later in this chapter.
- Atterburg limits and COLE tests. Although these tests are used by engineers, the soils scientist should try to coordinate his own sampling and testing schedule with the engineer. If the engineer or other members of the interdisciplinary team recommend additional tests, these should be included in the same lab analysis contract.

What fertility analyses should be conducted?

Analyses of nitrogen, phosphorus, potassium, certain trace elements, presence of calcium, magnesium, and sodium, and cation exchange capacity are commonly done on soils and overburden to determine nutrient levels.

Discussion:

Table 5 outlines the types of fertility tests used. Refer to this table while reading the following descriptions.

Tests for nitrogen, phosphorus, and potassium are recommended on both soils and overburden to detect deficiencies. Especially in dry climates, knowledge of the natural fertility of the soils and overburden is important in making manage-

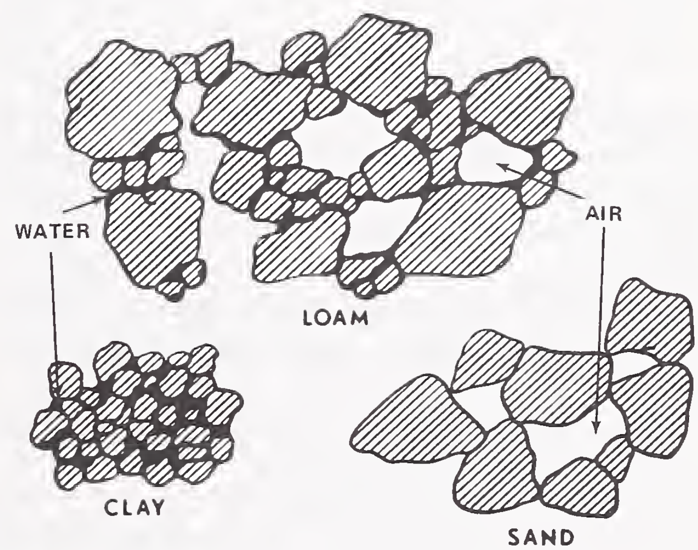

Figure 5. Clay has a greater water-retention capacity than loam; sand has less water-retention capacity than both loam and clay. (Utah State University)

Table 4.—*Laboratory analysis of physical characteristics*

Lab Test	Soil	Overburden
Texture	S[1]	Yes
Dispersion	No	S
Weatherability, slaking	No	S
Water-retention capacity (as measured by bars)	S	S
Saturation percentage	S	S
Hydraulic conductivity	S	S
Atterburg limits liquid limit plastic index	Consult Engineers	
COLE (Coefficient of linear expandability)	Consult Engineers	

[1]S: In special situations.

ment decisions for handling these materials. This is because there may be insufficient moisture to put the fertilizer into solution and make the nutrients available to the plants. In addition, some laws may require analysis of N, P, and K in the soils and overburden.

> **Exception:** It has been noted that because of the expense of selective handling of materials, it may be cheaper to apply the appropriate fertilizer after mining activity ceases rather than trying to separate out fertile zones in the overburden during mining.

Nitrogen tests—

- Mineralizable N is of particular interest when subsoils or geologic material may later be used as a plant-growth medium because it may indicate fertility problems undetected by overburden testing for organic matter or total N.
- It is very difficult to make N fertility interpretations from organic matter tests on the overburden.

Phosphorus tests—

- Plant-available phosphorus tests seem to work well for both soils and overburden.
- Sodium bicarbonate extraction is recommended for use as a phosphorus test on neutral and calcareous soils; the Bray No. 1 test is recommended on acid soils.

Trace elements—

- These tests should be run if the soils scientist thinks these elements may be deficient or present in toxic amounts; however, interpretations for most native species have yet to be worked out.

Lime, qualitative test—

- This acid test can be run to determine the presence of lime in the soils and overburden.

Cation exchange capacity—

- This test can be run if more information is needed about the cation exchange capacity of clays and organic matter in the soils and overburden.

What salinity-sodicity or acidity tests should be run?

Tests for salinity-sodicity include pH, soluble salts, water soluble ions, sodium adsorption ratio, exchangeable sodium percentage, water soluble anions, and gypsum. Acidity tests in-

Table 5.—*Soil fertility tests*

Test	Soil	Overburden
pH	Yes	Yes
Nitrogen		
Organic matter	Yes	Yes[2]
Total N	S[1]	S[2]
Soluble N	Yes	Yes
NH_4, NO_3		
Mineralizable N	S	S
Phosphorus		
Plant available	Yes	Yes
$NaHCO_3$ on neutral and calcareous soils		
Bray No. 1 on soils with pH less than 6		
Potassium		
Plant available	Yes	Yes
Iron, zinc, manganese, selenium, boron, copper (DTPA extractable)	S	S
Calcium, magnesium, sodium	S	S
Lime		
Acid test (qualitative)	Yes	Yes
Quantitative	S	S
Cation exchange capacity	S	S

[1]In special situations. [2]Interpretations difficult.

clude pH, qualitative and quantitative sulfides, and acid-base equilibrium. The initial test for either alkaline or acidic soils or overburden should always be pH. If soils or overburden shows a pH greater than 7, run tests for salinity-sodicity; if the pH is less than 6, run tests for acidity.

Discussion:

See table 6 for tests recommended for salinity and acidity characterizations. Salinity problems often occur in coal mining in the West. If the pH indicates a salinity-sodicity problem, it is recommended that the sodium adsorption ratio and exchangeable sodium percentage tests be run together to determine their relationship, rather than trying to infer exchangeable sodium percentage from sodium adsorption ratio. It should also be noted, however, that the exchangeable sodium percentage test is quite expensive.

- Water soluble anions. These tests help determine more about the relationship of water quality to soils and overburden.
- Gypsum. If gypsum is known to exist in the profile, problems foreseen from high sodium in the soils or overburden may be lessened.
- Acidity tests. These should be run if the pH value is below 6. Problems associated with acids occur particularly with sulfide minerals—the heavy metals of copper, zinc, gold, and silver. If an acid problem is indicated, qualitative and quantitative sulfide tests, acid-base equilibrium, and lime requirement will provide more information.

What toxicity analysis should be done?

Tests that indicate toxicity include emission spectrography and tests for trace elements such as boron, molybdenum, and selenium. An indirect test is pH. Radioactivity tests are advised in certain situations (see table 7).

Table 6. — *Salinity-sodicity and acidity tests*

Test	Soil	Overburden
	Salinity-sodicity	
pH	Yes	Yes
Soluble salts EC on saturated paste	Yes	Yes
Water soluble Ca, Mg, Na, K	Yes	Yes
Sodium adsorption ratio	Yes	Yes
Exchangeable sodium percentage	S[1]	S
Water soluble anions CO_3, HCO_3, SO_4, Cl, NO_3	S	S
Gypsum	S	S
	Acidity	
pH	Yes	Yes
Sulfide, qualitative	No	Yes
Acid-base equilibrium	No	S
Lime requirement	S	S

[1] S: In special situations.

Discussion:

One way to determine whether trace elements should be analyzed is to run an emission spectrograph on selected cores to pinpoint elements that may need further analysis. Then, laboratory tests for such trace elements as boron, molybdenum, and selenium can be run if necessary.

Some trace element analysis may also be required by law. The effects of all trace element concentrations are difficult to interpret, however, with the possible exception of molybdenum. For example, it is difficult to interpret tests for copper and iron, because if the soil is acidic enough to allow these elements to become toxic, the soil is probably already so toxic with soluble aluminum that plant growth is adversely affected. Thus, a low pH value can be used as a rough indication of soluble aluminum concentrations—and possible aluminum toxicity.

Radioactivity tests are indicated if material exhibiting uranium emissions will be used as a plant-growth medium or will have water running through it. Sedimentary material overlying uranium, and perhaps coal, may have this problem.

PRODUCTIVITY

How are the results of soils and overburden tests used?

These tests become the basis upon which the soils scientist predicts the productivity of the material as a plant-growing medium after mining. Both greenhouse tests and field observations can be used to verify test interpretations.

Discussion:

Productivity evaluations are made by correlating documented knowledge of established soil series to the experience gained in the actual performance of those or similar soil materials in the production of crops or native vegetation. Greenhouse and field studies are used to verify these evaluations on a site-specific basis and to check for possible changes in performance as a result of a disturbance or an expected disturbance.

Greenhouse studies of soils are useful because they may indicate soil characteristics not pinpointed by lab or field tests. Greenhouse studies are generally needed only in special situations, however, such as when the results of soils tests appear conflicting or when more information about differences among the same kind of materials is needed. For example, if sandstone A produces 4 times as much vegetation as sandstone B in the greenhouse, then sandstone A is the better growth medium.

Greenhouse testing is done by taking soils samples from the site, putting them in a greenhouse, manipulating the samples so that the scientist can test various limiting factors, such as an N deficiency or pH, and then observing the soil's productivity under these conditions.

Greenhouse studies on overburden are particularly useful because, unless one can observe plant growth on a road cut or old disturbance, it is difficult to foresee how overburden will react as a plant-growth medium. The main disadvantage of greenhouse testing is that artificial temperatures and water controls in a greenhouse do not match natural conditions and thus soil

Table 7.—*Toxicity and radioactivity tests*

Test	Soil	Overburden
pH	Yes	Yes
Emission spectrography	S[1]	S
Boron (hot H_2O)	S	S
Molybdenum (NH_4-acetate)	S	S
Selenium (hot H_2O)	S	S
Radioactivity	S	S

[1]S: In special situations.

productivity measurements in a greenhouse can be misleading.

Agronomic interpretations can be used to evaluate greenhouse tests, although these interpretations are sometimes difficult to relate to native plant species.

Field studies are the most accurate way to interpret soils laboratory tests. Field studies include setting up strips in the field and field observations. For example, a site can be fertilized with nitrogen in narrow strips to observe the effect this fertilizer will have on plant growth in contrast to the nonstripped areas.

ERODIBILITY

Thus far, this discussion has focused essentially on more static characteristics of soils and overburden; however, various changes will take place in reclaimed soils over a period of years and decades. If the soils scientist can predict some of these changes, he can make better decisions on the quality and quantity of soils materials to save and respread as topsoil.

Three important soil changes that will occur over time include:

- Soil structure changes due to root action and increased humus content.
- Erosional losses.
- Migrations of salt or toxic elements on some sites. (For information on salt or toxic-element migrations, see chapter 7.)

How is erodibility predicted?

The universal soil loss equation can be used to predict erosion due to water. The Soil Conservation Service (SCS) wind erodibility groups can be used to predict wind erosion.

Discussion:

Factors important for evaluating water-erosion potential and a basis for developing erosion-control management practices have been combined to form the universal soil loss equation:

A = R K L S C P

where:

A = computed soil loss expressed in tons/acre/year.

R = the rainfall factor, a measure of the erosive force of specific rainfall.

K = the soil erodibility factor, a relative value, expressed from 0 to 1.0, which reflects the inherent water erodibility of a given soil.

LS = slope length and degree factors.

C = crop cover or management factor.

P = erosion control practice factor.

Numerical values for each of these factors have been set by the Soil Conservation Service (SCS). These values, however, are based on bare soils in a natural state. Currently the SCS is working on values for disturbed soils in the Western States.

K values are assigned based on the tendency of a soil to erode. In general, the K factor increases with silt in a soil and decreases with sand, clay, and organic matter. Based on this factor, recommendations on slope length and slope degree can be made. Or, if the soils scientist is faced with a steep slope problem, the K factor would help him determine what type of material might best be used on the surface of the slope to prevent erosion.

Because the K factors currently in use are for natural conditions, the soils scientist must realize that he is only getting a relative measurement when he uses these values to predict erodibility on a disturbed soil.

When evaluating wind erosion, the soils scientist can refer to the SCS wind erodibility soil groups. These can be used to predict what wind erosion hazards will be present if a certain material is put back on the surface after mining (see table 8).

Again, caution in relying on these predictions is necessary because recently disturbed soil, such as occurs after mining, may have a tendency to increase values over what will be found in SCS guides.

Another important erosion measurement is the "T value" or erosion tolerance level. This is the minimum expectable amount of soil that can be lost through erosion and still maintain the productivity level of the soil. The "T value" is the quality standard that management and mitigation are geared to.

K factors and wind erodibility groups must be analyzed in relation to the upper and lower limits of acceptable erosion established in the "T value." It should also be recognized that an acceptable erosion rate or loss in terms of soil productivity may not be within water-quality standards for sediment.

Table 9 can be used as a guide to determine

"T values" for soil material, considering the protection of both the investment of replaced soils and their productivity.

TESTS TO DETERMINE HOW MUCH SOIL MATERIAL TO STOCKPILE

Although most of the tests discussed in this section have been mentioned in the first part of the chapter, they are presented here in a slightly different form in order to call attention to the importance of deciding whether or not certain material should be saved from the site prior to mining, stockpiled, and then resurfaced on the site as topsoil after mining.

Questions considered by various reclamation laws and reclamation managers are: whether or not to save the topsoil and respread it; whether a "second lift" of subsoil materials should be saved; and how much material should be segregated and respread.

The reason the answer to the first question—whether or not to save and respread topsoil—is usually "yes" is that unsurfaced spoils often exhibit characteristics that are limiting or prohibitive to plant growth. These might include:

- Low infiltration rate, low water intake.
- Low water-conducting and water-retention capacity.
- Low fertility.
- Poor tilth (soil structure).
- Deleterious constituents, such as high concentrations of soluble salts or sulfides.

What tests determine surface-infiltration rate?

Indicators include shallow-infiltration test, percent dispersion, crust strength, texture, SAR, and percent organic matter.

Table 8.—*SCS wind erodibility potential of bare soils by soil groups*

Group	Soil Classes	Hazard
1	Sands	High[1]
2	Loamy sands	High
3	Sandy loams	Medium
4	Silty clays & clays	Medium
5	Loams, sandy clay	Slight
6	Silt loams, clay	Slight
7	Silty clay loams	Slight
8	Wet or stony	Slight

[1] Use Soil Conservation Service guides for specific values.

Table 9.—*Erosion tolerance limits related to thickness of replaced soil material (T values)*

Thickness of replaced soil material (inches)	Erosion tolerance limits (tons/acre/year)
40-60	4
20-40	3
10-20	2
less than 10	1

Discussion:

Percent-dispersion tests relate to surface sealing, are inexpensive, and thus are worthwhile tests to indicate surface-infiltration problems.

What tests determine water-intake and water-retention capacity?

Direct tests include deeper infiltration measurements, water-retention capacity, drainage, and unsaturated hydraulic conductivity. Indirect indicators are texture, SAR, and saturated hydraulic conductivity. The objectives of these tests: to determine how much water can be absorbed and retained by the spoil or overspread soils materials, and how fast water will move through spoils and soils.

Discussion:

Because, in many situations in the West, water supply is limited as a result of both climatic and soil factors, water-intake and retention capacities become important factors to consider when making resurfacing decisions. This is especially true when very coarse-textured spoils are involved.

At this time, there is no reasonably inexpensive, accurate and user-packaged test for unsaturated hydraulic conductivity that is suitable for reclamation decisions. Simple permeameter measurements, however, can be combined with water-retention data to get estimates of unsaturated hydraulic conductivity.

The drainage test is expensive; water-retention data are fairly inexpensive and are available on recent soil-series descriptions in soil surveys.

In addition to these tests, other information is necessary in order to make decisions on the soils' and spoils' predicted water-intake and water-retention capacities. For example, the soils scientist must have some knowledge of how much water the proposed plants will be able to use. This information can be obtained by observing water use on deeper, productive soils on areas near the proposed mining site. From this, the scientist will have a better idea of how much soil will be needed for resurfacing on the spoils.

What tests indicate fertility, tilth, and soil structure?

These tests have been discussed earlier in this chapter.

What tests are used to discover deleterious constituents?

Direct indicators are EC for salts, Ca/Mg ratio, and toxic-element tests.

Discussion:

If tests indicate that salts and toxic elements are not present, there is no problem. If the Ca/Mg ratio is too low, it can negatively influence plant growth.

How are the results of these tests, observations, and other data used to determine the quantity of material that should be stockpiled for later use as topsoil?

Some standards have been set by law. Where not dictated by law or where further information is necessary to make a decision on a particular site, two general sources should be pursued: (1) agronomic productivity data, species diversity, crop water-use data, and other ecological data on both productive and less productive, unmined soils in the immediate mining district; and (2) plot and "wedge" experiments with topsoil and/or subsoil materials spread over spoils. These experiments will yield both site-specific and general information on quantity questions.

Discussion:

"Wedge" experiments can validate assumptions reached in the analysis and evaluation of data. As an example of a "wedge" experiment to determine crop water-use and productivity on topsoil and subsoil, it was shown that where the underlying spoils exhibited a medium to high SAR and low hydraulic conductivity, placing 1 ft of soils over the spoils resulted in considerably less water use by various crop species than when 4 ft of soil materials were spread over the spoil. Of course, in some situations the ideal quantity of topsoil and subsoil may not be available. In these cases, physical and chemical treatments may be necessary to bring the spoils up to a quality that will support vegetation. For more on spoils analysis and treatments, see chapters 5 and 6.

An example of how data collected on a uranium mine site in Wyoming were analyzed to make surfacing and other reclamation decisions is shown in table 10. Table 11 provides general information on parameters to consider when

determining the suitability of soil material for salvage and resurfacing use.

SAMPLING METHODS

Proper sampling techniques are as crucial to adequate analysis of soils and overburden as are the selection of the tests that should be run. Some research is being conducted on using gamma probes, electric logging systems, and seismic units to analyze overburden without relying solely on drilling and lab analysis. Currently, however, most testing relies on core drills. Techniques and frequencies of sampling vary widely, but the following are some general

Table 10. — *Guide for soil capability classification of reclaimed areas (prepared for a uranium mine on the national grasslands, Medicine Bow National Forest, Wyoming)*

Capability class	Material suitability rating	Soil depth	Permeability of replaced material	Available water-retention capacity	Slope	Erosion tolerance limits	Climate		Index plants
							ETp 32^{o}	PE	
		Inches	*Inches/hr*	*Inches*	*Percent*	*Tons/acre/yr*			
I	Good	Greater than 40	.2-6.3	Greater than 7.5 inches for 60 inch soil depth. Greater than 1.5 inch/ft	0-1	Greater than 4	Greater than 20	Greater than 44	Mature corn or sorghum plus those below
II	Good and fair	30-40	0.06-20.0	Greater than 5.0 inches for 60 inch soil depth. Greater than 1.0 inch/ft. Greater than 1.25 inch in surface ft	0-6	3	Greater than 14	Greater than 31	Corn or sorghum for silage plus those below
III	Good and fair	20-30	Any	Greater than 3.75 inches for 60 inch soil depth. Greater than .75 inch/ft. Greater than 1.0 inch in surface ft	0-10	3	Greater than 10	Greater than 25	Small grains for grain and hay crops
IV	Good and fair	10-20	Any	Greater than 2.0 inches for 60 inch soil depth. Greater than 0.4 inch/ft	0-30	2	Greater than 6	Greater than 19	Marginal production of cultivated crops. Index includes those listed below
V and VI	Good, fair, and poor	10-20	Any	Greater than 2.0 inches irrigated. Greater than 4.0 inches dryland	0-60	2	Greater than 4ETp (irrig). Greater than 8ETa (dryland)	Greater than 10	Pasture, range, woodland. Soils respond to management
VII	Good, fair, and poor	10-40	Any	Greater than 1.0 inch dryland	0-75	2-3	Less than 4ETa (dryland)	Less than 10	Pasture, range, woodland. Soils do not respond to management
VIII	Good, fair, poor, and unsuitable	10-40	Any	Any	0-100	2-3	Less than 4ETa (dryland)	-	No production of value

recommendations and concerns noted by researchers.

How intensely should the soils and overburden be sampled?

Sampling intensity depends on State and Federal regulations; the amount of disturbance expected; problems foreseen on the site; and the sampling needs of other members of the interdisciplinary team. The object is to obtain a general knowledge of the soils and overburden and to detect inhibitory zones in the overburden.

Discussion:

It is recommended that the major soil horizons be sampled. State or Federal regulations,

Table 11. — *Soil material suitability for salvage and reclamation use*

Definition: Suitability, as defined, is the qualities and properties of natural soils or soil material that chemically and physically provide the necessary water and nutrient supply for the top growth and root development of plants.

Criteria: The following groups of ratings are indicators of potential quality of natural soil profiles, certain soil horizons, or the underlying parent material, disregarding nutrient levels.

	Levels of suitability[1]			
Major parameters	Good	Fair	Poor	Unsuitable
USDA soil texture	Fine sandy loam, very fine sandy loam, loam, silt loam, sandy loam	Clay loam, sandy clay loam, silty clay loam	Sandy, loamy sand, sandy clay, silty clay, clay	Clay textured soils with more than 60% clay
Salinity (mmho/cm)	Less than 3	3-6	6-9	More than 9
Alkalinity (exchangeable sodium percentage, ESP)	Less than 4	4-8	8-12	More than 12
Concentration of toxic or undesirable elements, i.e., boron, selenium, arsenic, % lime, etc.	Very low	Low	Moderate	High
Soil pH	6.1-7.8	5.1-6.1 7.9-8.4	4.5-5.0 8.5-9.0	Less than 4.5 More than 9.1
Additional parameters to be evaluated				
Moist consistency	Very friable, friable	Loose, firm	Very firm, extremely firm	
Coarse fragments, % by volume	0-10	10-20	20-35	More than 35
Available water-retention capacity (inch/inch)	More than 0-16	0.08-0.16	Less than 0.8	
Permeability (inch/hr)	0.6-6.0	0.2-0.6	Less than 0.2 or greater than 6.0	
Organic matter (%)	More than 1.5	0.5-1.5	Less than 0.5	
Soil structure	Granular, crumb	Platy, blocky, prismatic	Massive, single grain	

[1] Ratings may be raised one class if soil amendments or management practices can be applied to overcome the limitations.

however, may require that transition horizons also be sampled. In particular, any horizon that contains crystalline salts should be sampled.

If there is not enough time between announcement of mining and commencement of work to sample and complete lab analysis—and there is no way to negotiate for more time—soil characteristics may have to be inferred from other, similar areas where series or phases of families have already been established. The intent is to characterize the soils and overburden on a representative basis, which is a judgmental assessment that relies on professional experience. The techniques are the same as in soil-mapping work, which is satisfactory if 85-percent accuracy is maintained.

Normally, sampling intensities are too low to assure complete accuracy in predicting inhibitory zones—i.e., zones in the overburden that would prevent or limit plant growth if used as a growing medium. For example, work done at Montana State University indicates that successful (90 percent) characterization of the location of inhibitory zones was attained only when the intensity of the grid sampling approached 100-200 ft between sample sites (see fig. 6). The reason for this is that inhibitory zones, such as pockets of highly saline material, will often be found in locations not predicted by examination of rock structures obtained from more widely spaced core samples.

This type of sampling intensity is very expensive, however, and is probably not feasible in most mining situations. Thus, sampling efforts may have to be intensified during postmining spoils analysis to identify and handle the inhibitory material that may surface (see chapter 5).

One alternative to such intense grid sampling is an incremental system of drilling, in which a small number of holes is sampled and evaluated, and then more drilling is ordered based on the results of the first cores. In other words, random samples are taken on a less intense basis and then the soils scientist and geologist make a decision on the level of further sampling needed based on the first round of samples.

Another method used is to classify surface materials (dark shales, light shales, sandy materials, etc.) before sampling because often these surface materials will correlate with the overburden strata found under them. This procedure can reduce the number of samples needed as compared to a random or fixed-grid type of sampling.

How should the soils samples be sent to the lab?

Paired profiles and individual samples of each horizon should be sent to the lab if possible.

Discussion:

Paired profiles are two complete cores representing two entire profiles and taken from the same sampling area. Then, the profiles are separated into horizons, and each sample pair of horizons is analyzed. In this way, results from the lab tests on the paired horizons can be compared.

Additional Information:

Recommended references for this chapter include:

"Procedures Recommended for Overburden and Hydrologic Studies of Surface Mines," by James Barrett, Paul E. Deutsch, Frank G. Ethridge, William T. Franklin, Robert D. Heil, David B. McWhorter, and Daniel Youngberg. Colorado State University and USDA For. Serv., Douglas, Wyo. December 1978.

"Laboratory Methods Recommended for Chemical Analysis of Mineland Spoils and Overburden," U.S. Dep. Agric. Handbook 525.

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"Soil Interpretations in the Soil Survey," by Charles E. Kellogg, USDA Soil Conser. Ser., Washington, D.C. April 1961.

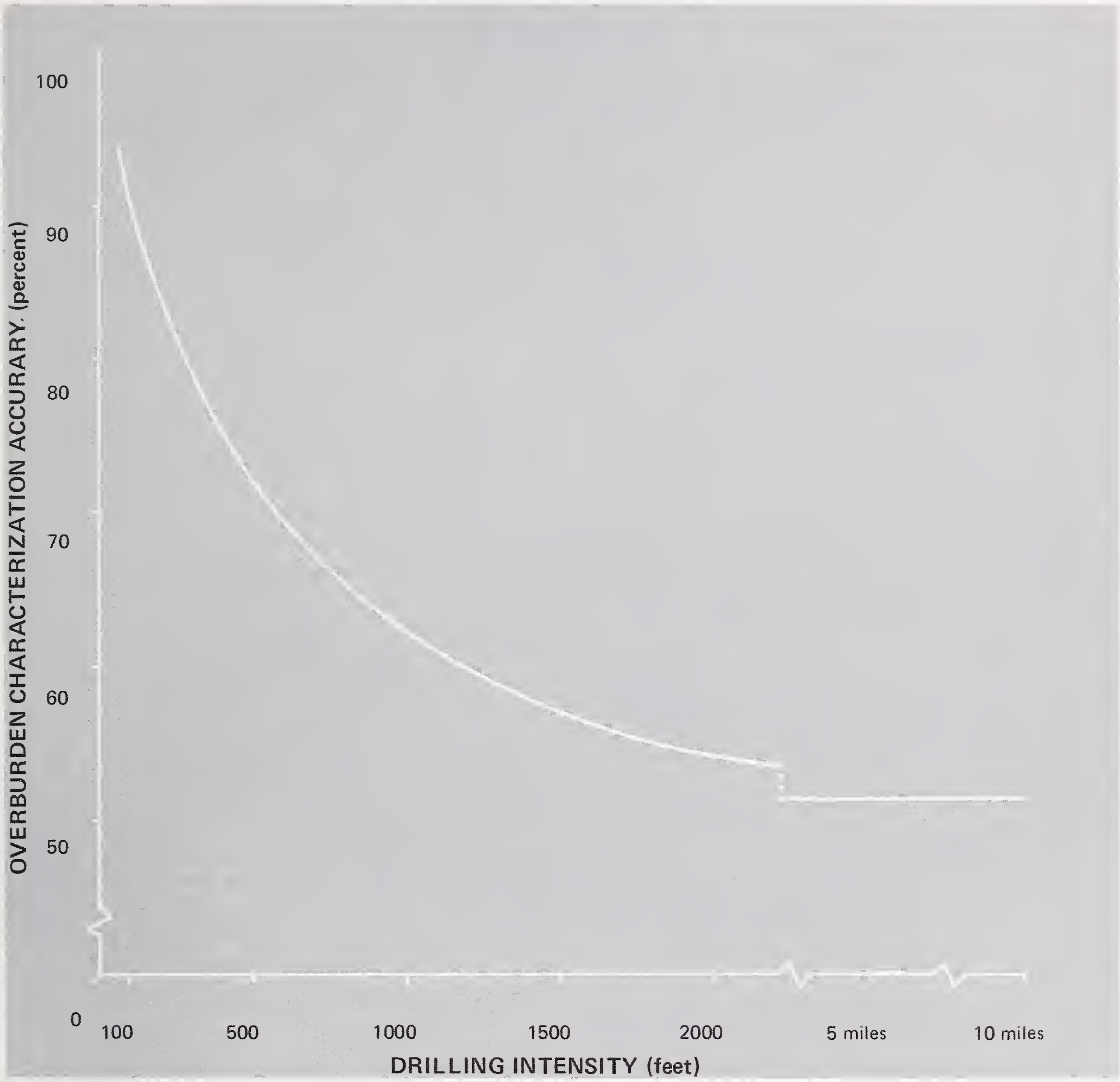

Figure 6. Accuracy in characterizing overburden based on sampling intensity. (D.J. Dollhopf, Montana State University)

Chapter 3
SELECTING STORAGE AREAS

Chapter Organizer: Sonny J. O'Neal

Major Contributors: Sonny J. O'Neal, James J. Butler

An important component of the mining plan is the selection of storage sites for the mined materials. Although the mining operator generally selects the site best suited to his needs, approving this selection is the responsibility of the land manager, based on recommendations from the soils scientist and other members of the interdisciplinary team. The ID team should also be prepared to suggest alternative storage areas. This process should be followed regardless of the size of the proposed operation.

What are the goals of storage area selection?

In general, the goals for selecting storage areas should include: providing safety and preventing endangerment of adjacent property, life, and resources; accommodating reclamation that will provide for land uses and esthetics compatible with surrounding lands; assuring compliance with State and Federal regulations; providing for adequate access to and from the storage area; and considering the mining company's feasibility estimates.

Discussion:

Not all State laws require that ultimate reclamation, including the reclamation of storage areas, be compatible with surrounding land uses. By working with the mining operator to design a suitable storage area and by identifying alternative storage sites, however, the land manager should be able to insure that the site will be compatible with its own land-management goals. Of course, any specific laws pertaining to selecting a storage area, such as Environmental Protection Agency (EPA) regulations on sediment, should be outlined well before site selection begins.

What kinds of storage areas will the soils scientist aid in selecting?

Storage areas may be temporary or permanent, fluid or dry. Some storage areas may simply be filled by dumping; others will be constructed in lifts and mechanically compacted at various stages. Selection criteria will vary based on the type of storage planned. For example, if storage will be temporary, the soils scientist should ask if it can be reclaimed after the material is removed; if permanent, he should determine if the material itself can be revegetated, and if suitable soil material should be stripped from the storage site for rehabilitation use.

Discussion:

Temporary storage areas include:

- Temporary storage of topsoil until it can be replaced on the mined site.
- Temporary storage of overburden. Although not a common practice, there are situations when overburden must be stored and later placed in the mining pit as backfill.
- Temporary storage of ore prior to shipment to a processing plant.

Permanent storage areas include:

- Permanent storage of overburden. Mine operations with large stripping ratios and deep pits require external waste dumps that are permanent; i.e., the material cannot be placed back into the pit as backfill. Another case in which the mine is not returned to its original contour by backfilling is when it may be mined again several years later.
- Tailings ponds. Fluid material, such as mill tailings, is usually impounded behind embankments for drying if it cannot be pumped back into the mine.

Prior to storage selection, what factors should be analyzed by the soils scientist in cooperation with the ID team?

The soils scientist should work with the ID team to provide information on:

- *Whether storage needs will be permanent or temporary.*
- *The quantity and characteristics of the material to be stored.*
- *Potential toxicity or stability problems once the material is in place.*
- *Suitability and feasibility of removing topsoil from the site for later use in reclamation.*
- *Materials placement methods.*
- *Recommended slope and aspect of the fill.*
- *Current vegetative productivity of potential storage areas and predictions on the success of reclaiming the storage area.*
- *Access from the mine operation to the storage site. Also, consider removal access if the storage is temporary.*
- *Effects of existing topography on future stability and reclamation.*
- *Effect of wind and water on the storage site and the feasibility of erosion control practices to prevent sediment from leaving the site.*
- *Effects of drifting snow and whether snow management is needed.*
- *Drainage effects on stability and reclamation.*
- *Effects of material storage on adjacent land uses.*
- *Effect of leachates from the storage material entering the water supply.*
- *Effect of existing vegetation on waste dump stability—clearing or other site preparation needs.*

Discussion:

Both physical and chemical characteristics of the material to be stored should be known in order to design a stable dump that will support vegetation, especially if the storage area will be permanent. Although complete accuracy in characterizing the material that will be stored is not possible until it is actually in place, a broad estimate of its characteristics, including erodibility, acidity, or alkalinity, and competency, can be determined based on analysis of the soil and overburden at the site to be mined. If toxicity and competency problems are foreseen on a site, it should be avoided as a storage area, or the dump design should adequately resolve these problems.

Generally, the existing topsoil at the mine site will be the most productive growing medium for plants and should be stockpiled for placement back on the site as topsoil.There are cases, however, when analysis of the overburden will identify substrata that can be used as a plant-growth medium in lieu of topsoil. If this is the case, consult with the mining engineer on the feasibility of stockpiling these materials for later use as topsoil, if they cannot be placed on top during the mining process.

Current productivity of potential storage areas and the potential for reclaiming the storage area should be determined with input from the vegetation specialist. The ID team should decide if the site's plant productivity can be sacrificed to becoming a storage area. Characteristics of both the current site and the material planned for storage at the site will aid in determining reclamation potential of the storage area.

It is recommended that the storage area be no steeper than 3:1. The slope of the fill must not be so steep that, as the dump settles, sediment loss and surface slides occur (fig. 7). The slope should also be shaped in such a way that it is compatible with surrounding land formations and should not create a barrier to wildlife habitat or water-drainage patterns. Again, interaction with the ID team is mandatory.

Consideration should also be given to the direction of the slope. For example, a south-facing slope will be more difficult to revegetate in arid climates because of the higher temperatures common to southern exposures. North-facing slopes may have disadvantages in cold climates where growing seasons are short.

Wind can be a problem if fine-grade materials are left on the surface of the storage areas. These materials can then blow onto and pollute adjacent land and watercourses. If soil erosion from water movement is foreseen, the soils scientist and mining engineer should determine if a sediment basin below the storage area can be built to catch eroding sediment, or if land shaping will prevent or minimize erosion.

Regarding the effects of leachates from the stockpiles, consult with the hydrologist to predict the possibility of leachates entering and adversely affecting water supplies.

Additional Information:

Refer to chapter 2 of this guide for tests recommended to characterize soils and overburden.

What information should the soils scientist

provide after the site, or the most viable alternatives, have been chosen?

At this point, the soils scientist may need to aid the land manager and the ID team in conducting site and foundation investigations in more depth, and making recommendations for materials handling. (See chapter 4.)

Discussion:

If more information is needed to make a final decision on the acceptability of the storage site, subsurface investigations may be needed. The following information may be available from the mining engineer or engineering geologist:

- Depth to bedrock.

Figure 7. A potential result of very steep dumps is rill erosion and mass slumping from saturation due to snowmelt water.

• Materials properties (distribution analysis by three-dimensional mapping of materials, shear strength, and consolidation characteristics).

• Ground water.

• Bedrock properties.

Once the site has been selected, it is important to make sure that all existing vegetation will be removed from the site before any material is stored on it. If this is not done, the resulting decaying material may create a slippage plane and piping underneath the dump. Also, when organic matter is pressed onto the surface by fill material before it has decomposed, it tends to seal the soil material under it, and water will not percolate through it. Consideration should also be given to the possible effects of erosion from the site in the interim between removal of the vegetation and dumping the spoils.

Such factors as the chemical and physical reaction of the spoils once placed on the site should be predicted before placing mined material into the storage area. In addition, it is important to consider the color and texture of the material that will become topsoil on the site because this will affect vegetation growth. And, at this time, the possibility of selective handling of any toxic or inhibitory material should be considered. The following chapter will provide more information on selective handling.

Chapter 4
MATERIALS HANDLING

Chapter Organizer: Douglas J. Dollhopf

Major Contributor: Douglas J. Dollhopf

Correct handling of the soils and overburden by the mining operator is increasingly being emphasized in reclamation programs today, because reclamation implies reclamation from the bottom of the pit to the top and expressly considers the physical, chemical, and hydrologic characteristics of lands both before and after mining. For example, one reason for expanding reclamation efforts beyond simply producing stable and useful vegetation on the surface is the concern that mining operations may adversely affect the quality of ground-water resources.

This concern stems from the fact that, in places, the mineral seam itself was an important aquifer prior to mining. During mining, however, the mineral seam is effectively eliminated and replaced by overburden material from an adjacent mine cut. The aquifer then tends to reestablish itself in the new spoil medium, and it is possible that the ground water will take on, to a certain extent, the chemical characteristics of its flow medium. Thus, it is imperative to determine the location of chemically undesirable overburden zones to insure that materials from such zones are not deposited in the pit base where an aquifer may reestablish. (These zones will be referred to as inhibitory zones in this chapter.) It is also imperative that any undesirable overburden is not deposited within the plant-root zones if it is known that it will severely inhibit the revegetation process, or if the vegetation may accumulate certain chemicals that will harm livestock or wildlife when grazed.

Another concern, of course, is the cost involved in selective handling of inhibitory zones. For example, recent research indicates that selective handling may add from 12 to 53 percent to the direct operating costs of mining. Thus, based on premining analysis results, the mining operator and land-management team must decide the cost/benefit of such an undertaking.

How are inhibitory zones located?

Field and laboratory analyses of the soils and overburden will aid the soils scientist in estimating the extent and location of inhibitory zones in the material prior to mining. Additional observation and testing during the mining operation may also uncover previously undetected inhibitory zones.

Discussion:

As discussed in chapter 2, sampling methods cannot guarantee total accuracy in characterizing the overburden, unless a very intensive—and expensive—sampling program is undertaken. Because of these limitations, defining the extent of inhibitory zones may be the most difficult part of the materials placement program. In addition to the inaccuracy of most sampling frequencies, there are times when sample collection is only hours ahead of the dragline. For instance, the samples are collected from a blast hole drill rig. In contrast, preparation for any selective handling takes several days, when time needed for both chemical analysis and engineering plans is taken into account.

To help ease this dilemma, the following procedures are recommended:

- Develop sampling and rapid analysis methodology to adequately define problem zones within the overburden.
- Determine the premining hydrologic characteristics of the site in order to estimate postmining conditions. Work with a hydrologist on these characterizations.
- If possible, develop a plan to alter normal mining operations, when necessary, in order to provide sufficient time for sample collection and analysis.
- Work with a mining engineer on these plans.

Must inhibitory zones always be selectively handled?

No, research shows that unless an inhibitory zone constitutes 15 percent or more of the overburden material, it may be sufficiently diluted in the materials handling and mixing process and not adversely affect ground water or plant growth.

Discussion:

Because selective burial of inhibitory zones in the overburden in order to hydrologically isolate such materials may cost 1.1 to 1.5 times more than the normal spoiling operation, it is important to determine whether normal dragline spoiling can sufficiently mix problem materials and produce an environmentally acceptable spoil profile.

Prior to strip mining, overburden is usually composed of a more or less orderly array of approximately horizontal rock strata. These strata may contain material that exceeds levels considered potentially harmful or inhibitory to plant growth; however on the undisturbed site, they are generally below the biologically active surface zone.

During mining, there is a tendency for the stratigraphic sequence to be inverted as the overburden is transferred into spoil piles; however, such strata are not transferred as whole units. Rather, several strata may be crossed by the dragline bucket as it is filled and successive loads are collected from varying depths. Digging and spoiling of the overburden tend to mix the original stratigraphic conditions. The result is spoils of increased chemical and physical homogeneity; hence, potential toxicity may be reduced to acceptable levels, which are neither harmful to plant growth or to water quality.

Research has shown that when the problem material constitutes less than 5 percent of the total overburden volume, such material is essentially not detectable in the spoil pile. Problem materials constituting 5-15 percent of the bulk mass could be detected in the spoil mass 50 percent of the time, but the volume of the problem material detected was generally less than that found in the overburden, indicating partial dilution. Problem material exceeding 15 percent of the overburden volume, however, was always detected in the spoil mass, but usually to a lesser degree than that found in the undisturbed overburden. These criteria were developed at a mine which used a large dragline to excavate overburden. Other methods of excavation, such as truck and shovel, may change these criteria.

How can maximum dilution of inhibitory material be achieved without selective handling?

It has been found that scatter spoiling may produce a better degree of mixing and dilution, although the difference is not great. Normal spoiling has an effect similar to scatter spoiling. Dump spoiling generally results in less mixing of inhibitory zones and thus should be minimized in dragline spoiling operations.

Discussion:

Scatter spoiling generally spreads each bucketload of material over an area in the spoil pile about 45-65 yd long by 10 yd wide. In order to spread the overburden this widely, the dragline continues its swing while unloading. The operator controls the rate of the load leaving the bucket and, hence, the amount of spreading. Normal dragline spoiling is similar to scatter spoiling except that the budketload of material is cast over a smaller area—approximately 20 yd long by 10 yd wide.

Dump spoiling occurs when the material is dropped when the bucket is nearly stationary, and thus the dumped material forms a cone. Generally, dump spoiling is used at the bottom of a backfill pit because it provides a base of material that is less likely to slump or settle. Once this initial fill is in place, normal or scatter spoiling methods are generally used for the bulk of the overburden.

If inhibitory zones in the overburden must be selectively handled, how is this done?

The mining engineer, hydrologist, and soils scientist should work together to determine where and how the material can be selectively buried. Two considerations are: should the material be buried at some intermediate depth in the spoils pile; or should it be buried and isolated from the hydrologic environment by an impermeable layer of material?

Discussion:

Selective handling of inhibitory material may add about 12 percent to the direct operating

costs of mining; if the material is capped, costs may increase by about 53 percent. Thus, it is important to consider the cost/benefit of such an operation.

An understanding of the shallow ground-water system is also essential for evaluation and implementation of selective overburden handling. A determination of such factors as post-mining water levels, recharge, and water-movement characteristics in both the undisturbed and reconstructed aquifers is necessary to decide how the material should be selectively handled and if it must be capped. If it is to be capped, capping material must be available and suitable.

In general, if the inhibitory material is in a wet environment, where an aquifer may move through it, it may be desirable to envelop the material with a semi- or relatively impermeable clay. The soils scientist and engineer can contribute their expertise to accomplish the project.

As one example, the following procedure was used on a coal-mine site that was hydrologically active—it tended to form an aquifer through the base of the pit—and the overburden contained a zone of excess salts. (Also see fig. 8-21.)

- Quality material was placed in the base of the pit to a thickness that would be greater than the expected thickness of the reconstructed aquifer—in this case, 40 ft.
- The salt material was selectively dug up and applied to the top of the 40 ft fill.
- At times, the dragline was shut down so that a dozer could go into the pit and grade the materials.
- A clay cap was constructed on top of the salt so that any percolating waters or a perched aquifer would not interact with the salt material. Once again, the dragline was periodically shut down so that scrapers could bring in the clay from another part of the mine.

In essence, then, the problem zone was buried above the aquifer and yet below the ultimate root zone. Obviously, this was a very expensive operation.

It should also be noted: If the material is to be selectively handled, the techniques for doing this must be clearly communicated to the mining crew and equipment operators.

Figures 8-21. Demonstration of selective handling procedure at a coal-mine site in Montana. (D.J. Dollhopf, Montana State University, Research Report 125).

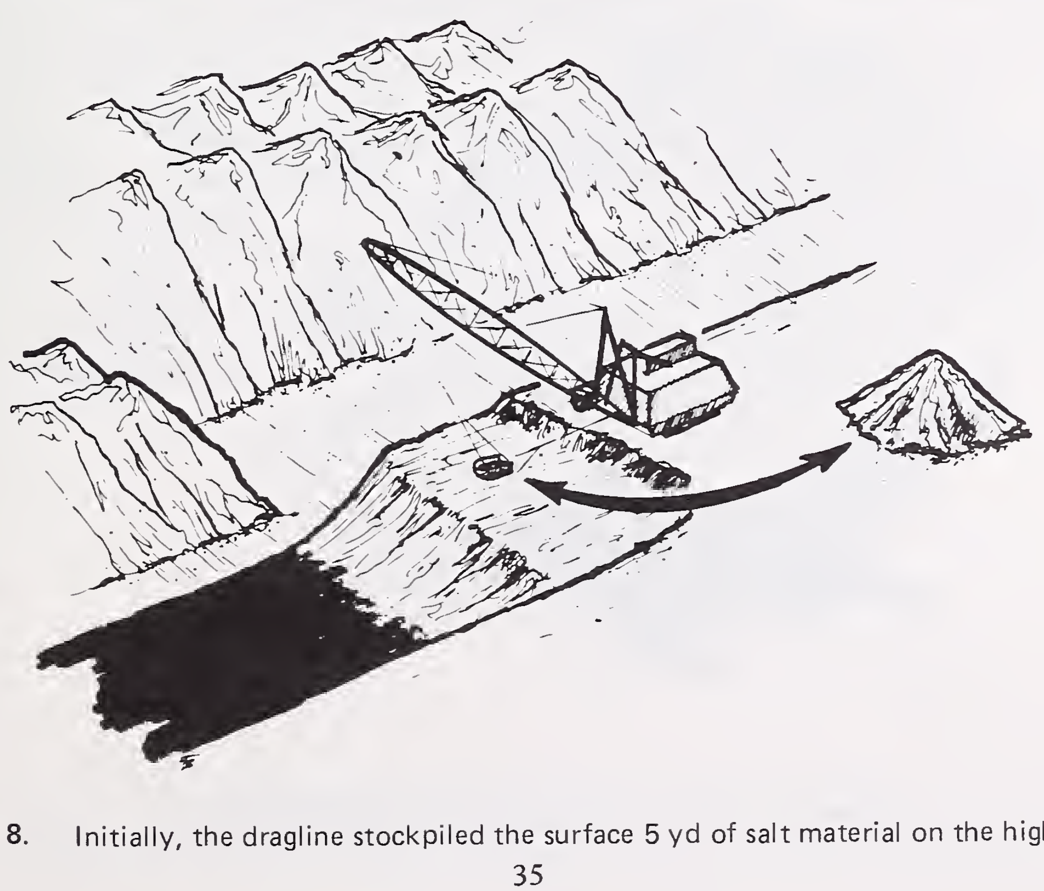

Figure 8. Initially, the dragline stockpiled the surface 5 yd of salt material on the highwall.

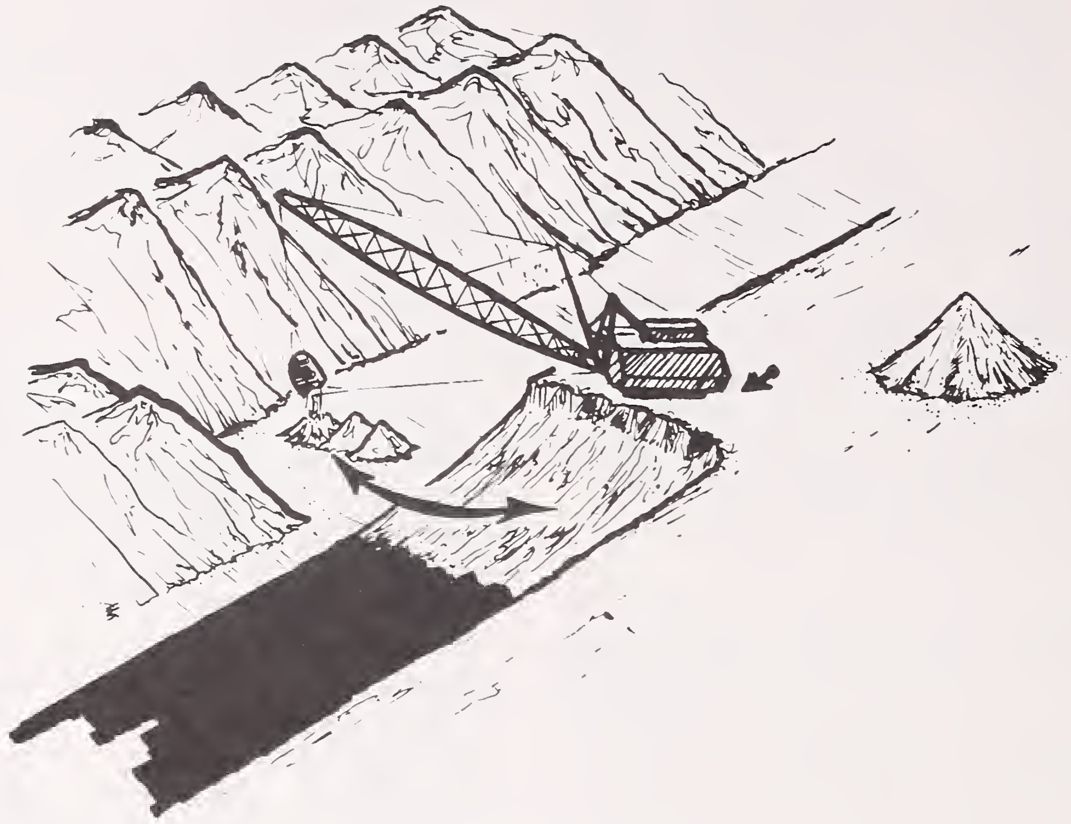

Figure 9. Overburden below the surface salt-affected zone was placed in the pit bottom as basement fill.

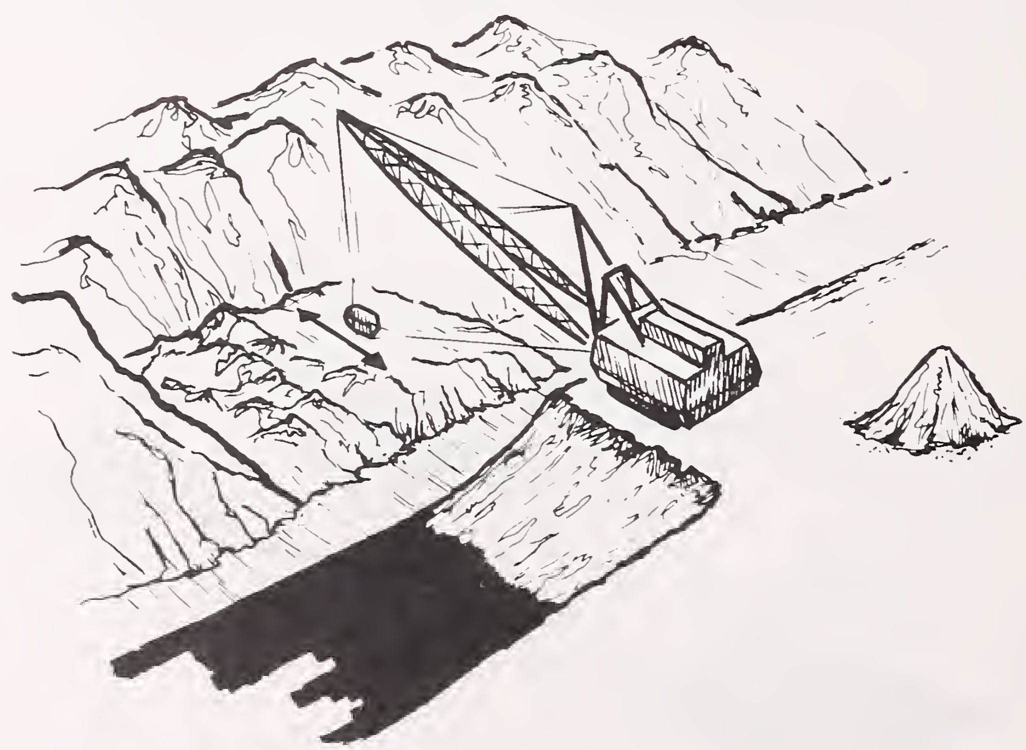

Figure 10. Leveling and shaping the basement material
with the dragline to reduce the work required by a dozer in grading these materials.

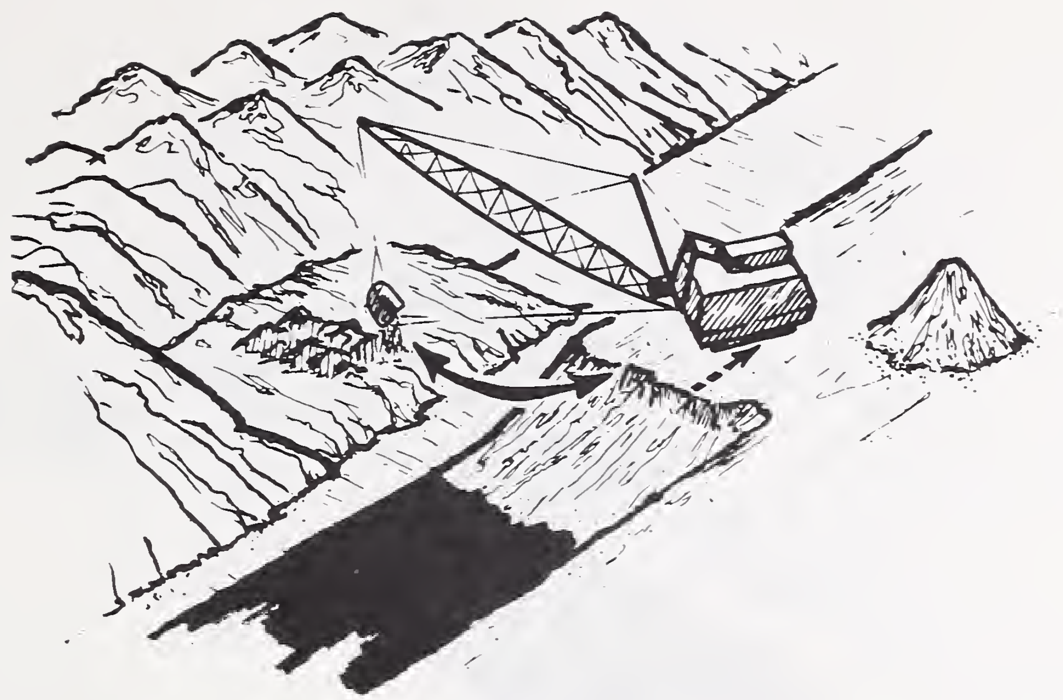

Figure 11. Direct deposition of saline material on the basement fill.

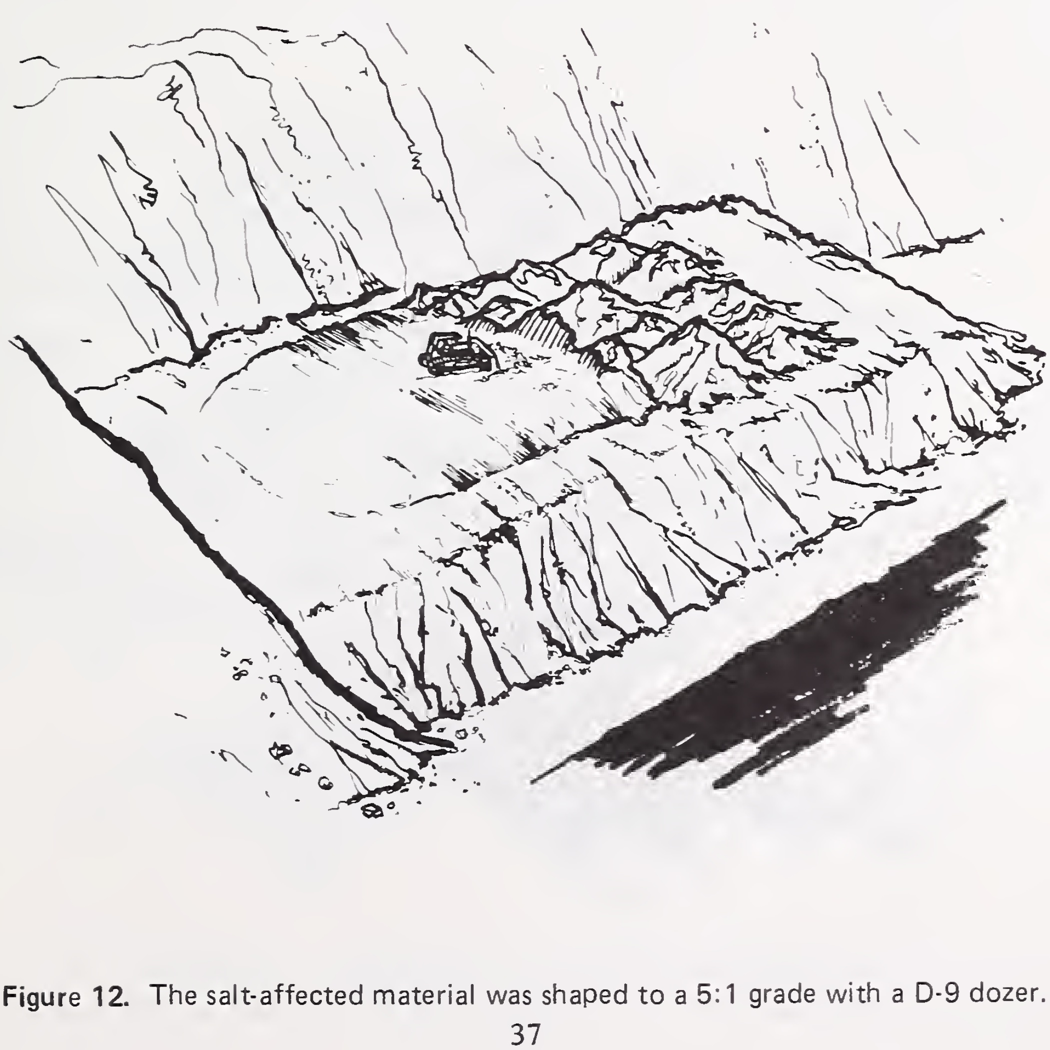

Figure 12. The salt-affected material was shaped to a 5:1 grade with a D-9 dozer.

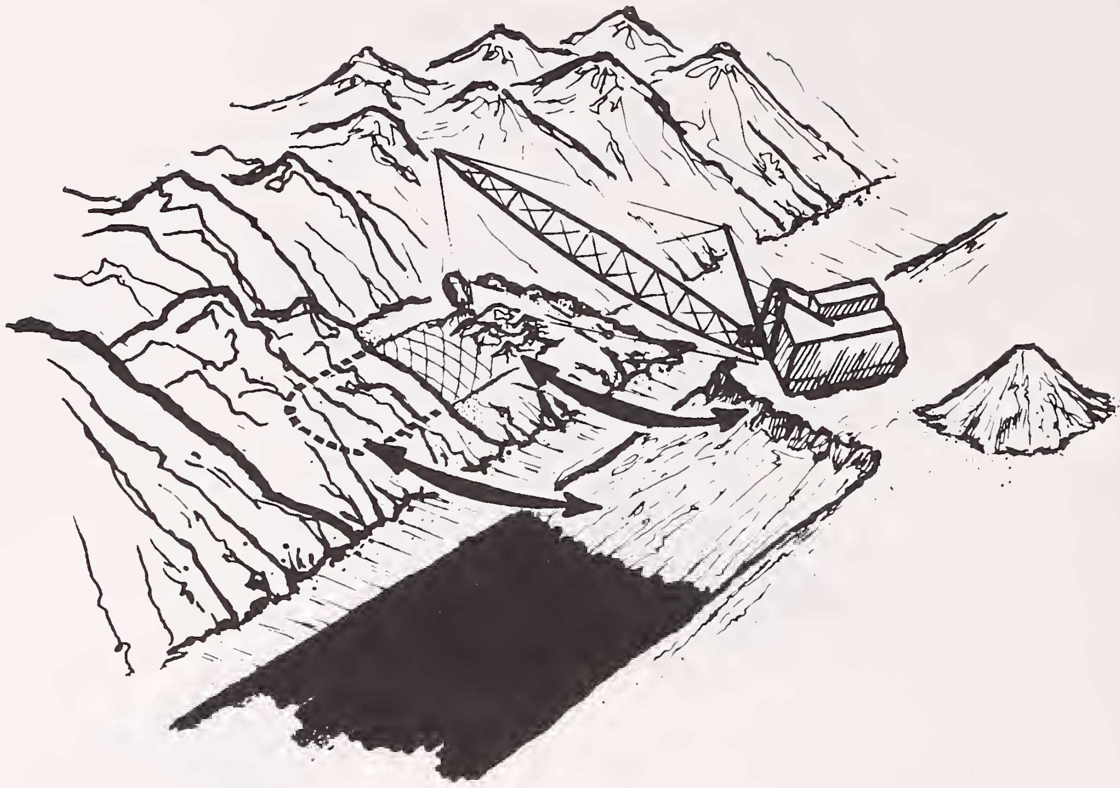

Figure 13. Burial of saline material (lower arrow) with nonsaline overburden.

Figure 14. Deposition of saline material from both the overburden and the stockpile.

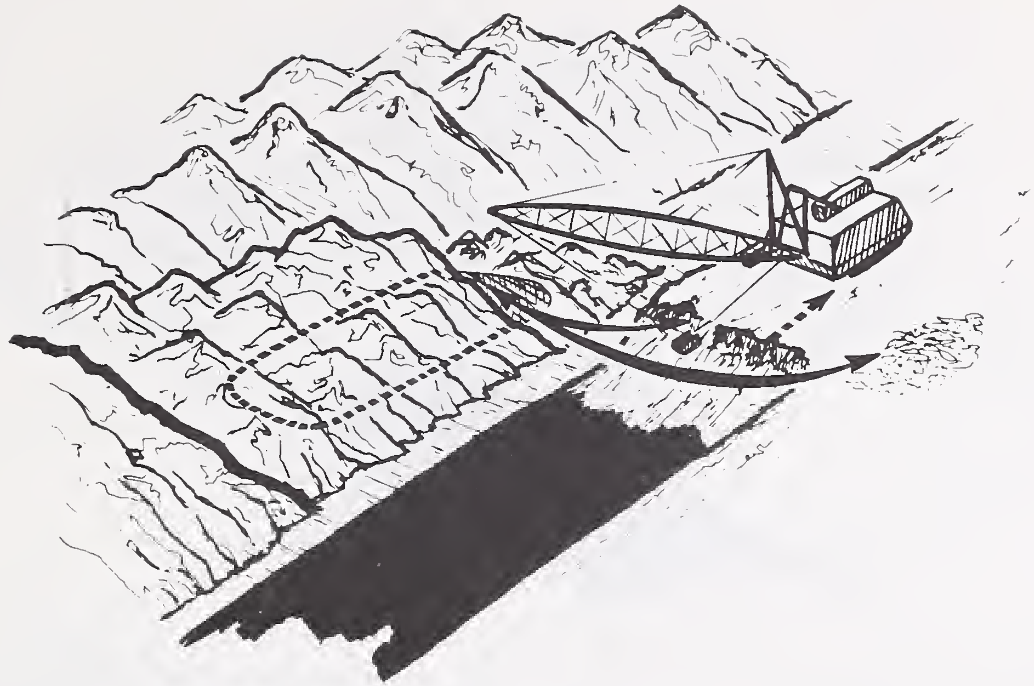

Figure 15. Most of the highwall stockpile was deposited on the basement fill towards the completion of the uncapped study.

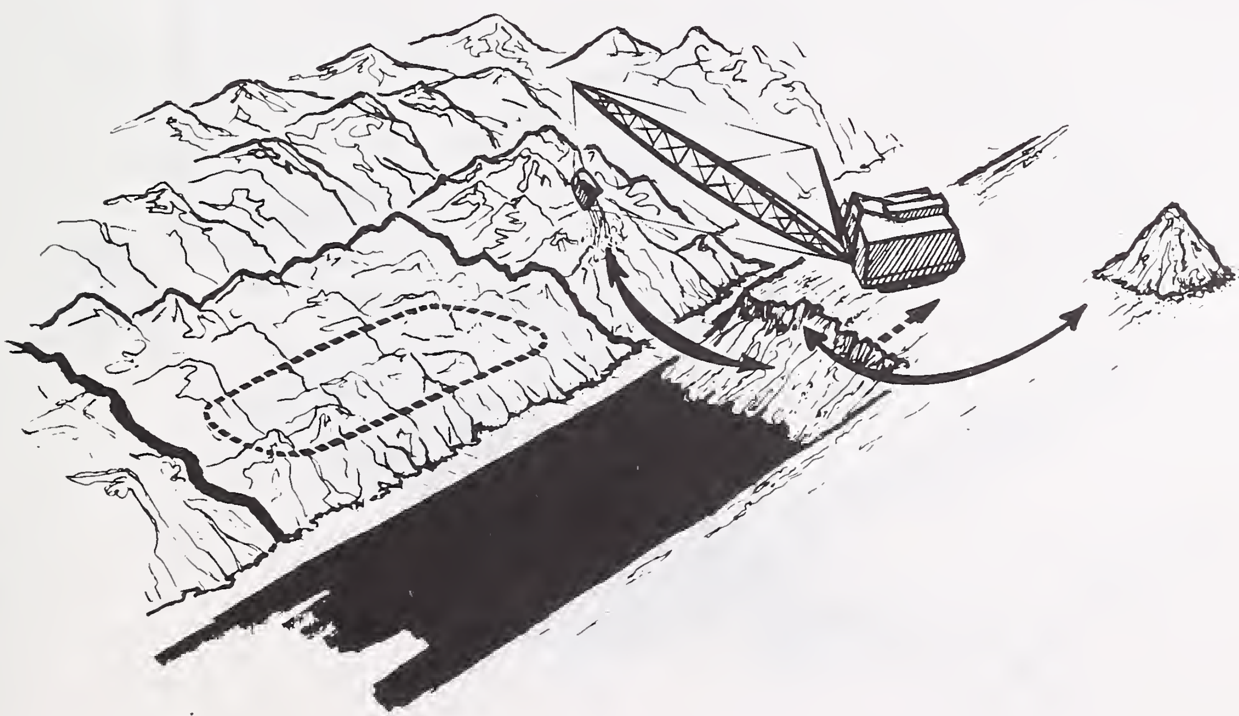

Figure 16. A buffer zone was constructed when the uncapped study was completed. During this phase the surface saline zone was stockpiled on the highwall.

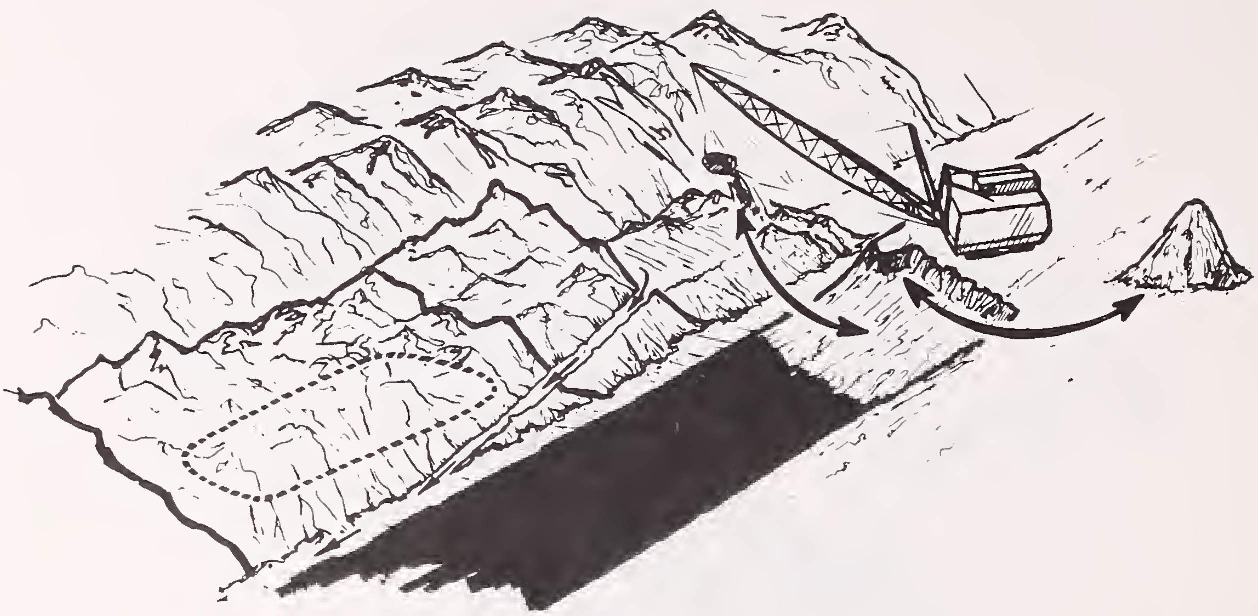

Figure 17. Following construction of the buffer zone, a 15-yd-thick basement fill for the capped research area was deposited in the pit bottom. During this process, the surficial saline zone was stockpiled on the highwall.

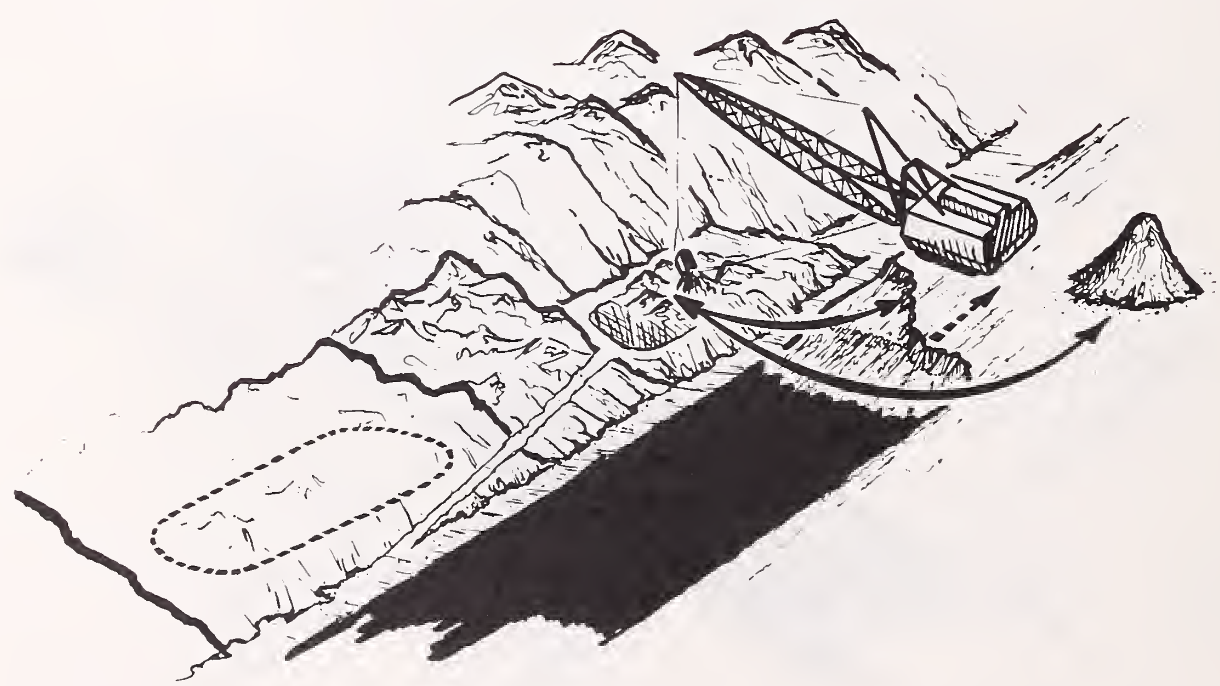

Figure 18. When a portion of the basement bench was completed for the capped study, the dragline deposited saline material over the basement from both the overburden and stockpile.

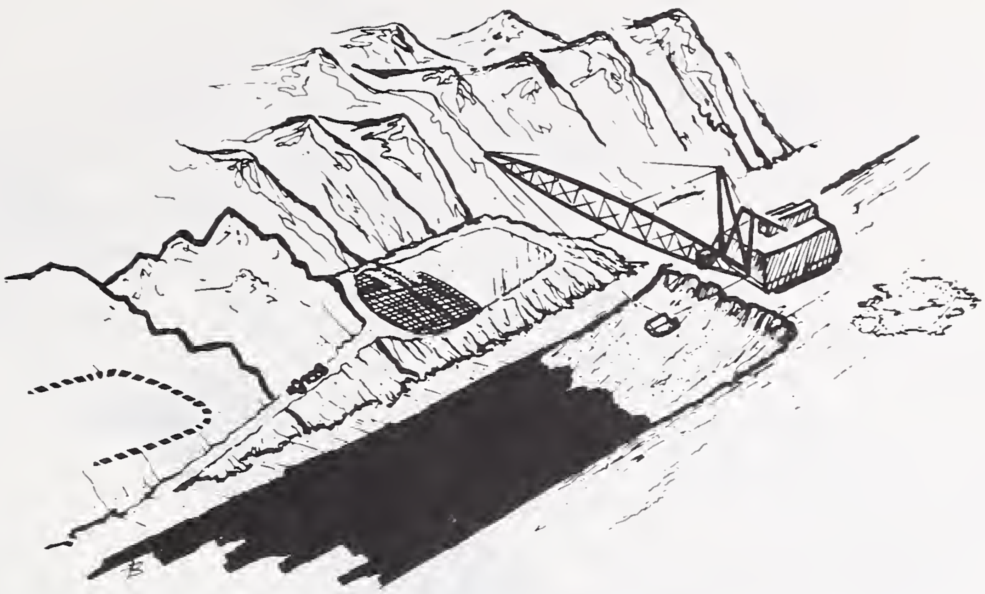

Figure 19. Clay located 110 yd from the demonstration site was applied to a depth of 2-1/2 ft by scrapers. The dragline had to shut down during this clay-capping operation.

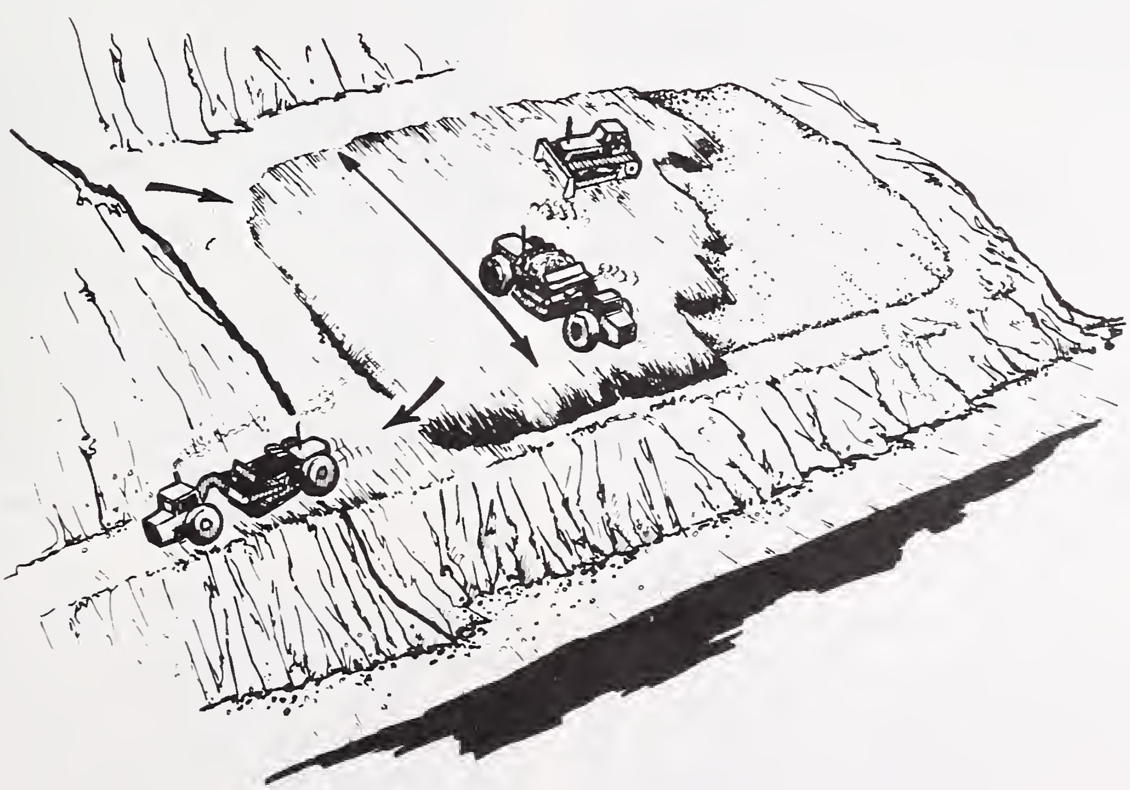

Figure 20. Loaded scrapers were used to compact the clay cap. A D-9 dozer shaped the cap to produce an umbrella effect over the saline material.

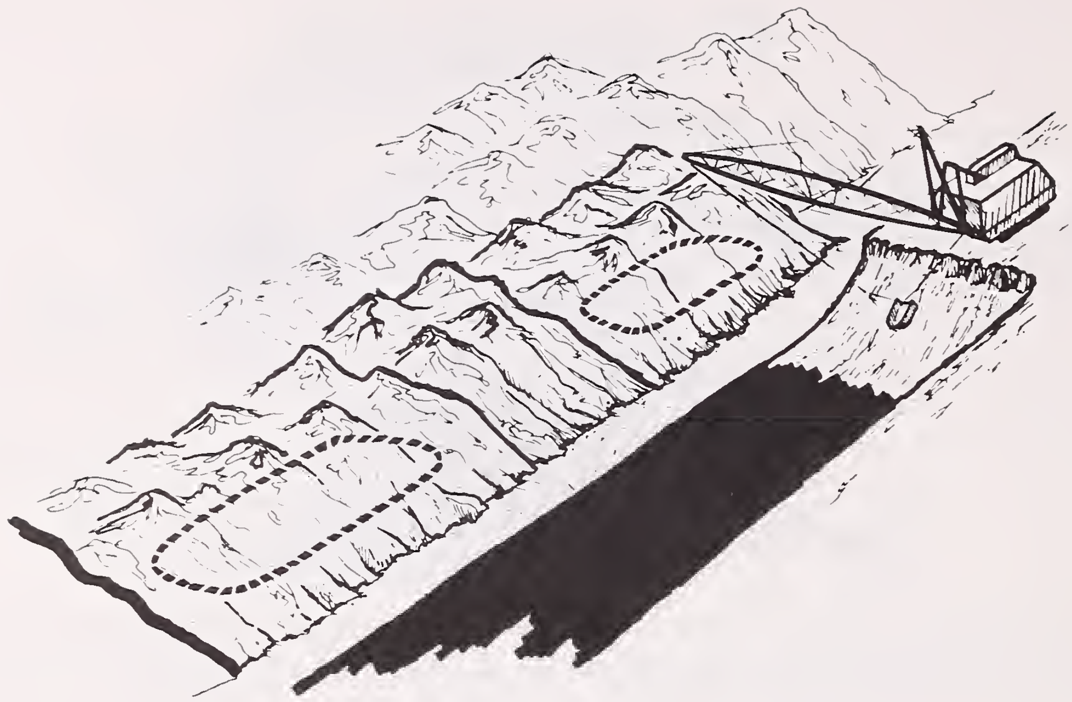

Figure 21. The uncapped and capped experiments were oriented as shown above at the conclusion of the demonstration.

Should topsoil be selectively handled?

Generally, yes, because this material is usually the most superior plant-growth medium and thus should be replaced on top of the spoils. The analysis process to determine whether the topsoil will be the best plant-growth medium is covered in chapter 2.

Discussion:

Because a suitable plant-growth medium is essential to rehabilitation, and soils develop very slowly in the arid West, the topsoil is a highly valuable resource. Topsoil can either be removed from the active mining area and immediately spread over freshly graded spoils, or it can be stockpiled for later application. The former method is preferable because fresh topsoil contains live seeds and plants that will take root and aid in stabilizing the site. In many cases, however, topsoil stockpiling is the only choice. If topsoil is stockpiled, it should be stabilized through grading, mulching, and possibly seeding it with a fast establishing, temporary grass.

In certain instances, a subsoil material may be identified as a suitable plant-growth medium. If so, and it is feasible to selectively handle it, the material can be stockpiled and graded on the surface of the spoils in the same manner as topsoil is handled.

Additional Information:

Tests to determine the quality and amount of topsoil material that should be saved and replaced on the mined site are discussed in chapter 2. More information on spoils surfacing is provided in chapter 7.

Information on selective handling techniques are provided in:

"Selective Placement of Coal Stripmine Overburden in Montana—II. Initial Field Demonstration," by D.J. Dollhopf, W.D. Call, C.A. Cull, and R.D. Hodder, Montana Agricultural Experiment Station, Montana State University, Bozeman, Mont. Research Report #125. June 1977.

"Selective Placement of Coal Stripmine Overburden in Montana—III. Spoil Mixing Phenomena," by D.J. Dollhopf, J.D. Goering, C.J. Levine, B.J. Bauman, D.W. Hedberg, and R.L. Hodder, Montana Agricultural Experiment Station, Montana State University, Bozeman, Mont. Research Report #135. June 1978.

Chapter 5
SPOILS ANALYSIS

Chapter Organizer: David G. Scholl

Major Contributors: David G. Scholl, E. Gary Robbins

As discussed earlier in this guide, soils and overburden analysis is necessary in the premining phase of the operation in order to predict what characteristics the spoils material will exhibit after mining. It also indicates whether any special handling will be required during mining. Another series of tests must be run, however, when the spoils are placed in the fill to determine if premining predictions were correct. Unfortunately, much research remains to be done in the area of correlation between spoils analysis and plant response. In addition, no systematic method of spoils classification has been fully developed. Some general principles have emerged, however.

What is the purpose of spoils analysis?

After the spoils have been placed in the storage area, they should be analyzed to pinpoint problems or beneficial characteristics and to determine if premining predictions and reclamation methods outlined in the mining plan are still valid. If not, some modification may be required in order to successfully revegetate and manage the site. In other words, these studies produce the new baseline by which the site can be managed.

Discussion:

When the soils and overburden were analyzed prior to mining, some indication of problems and opportunities in the spoils material may have been predicted. Once the material is in place, the spoils should be tested to see if the desired effect was achieved. For example, were problem materials buried below the plant rooting zone and above any important aquifers, or were they diluted during the mining process?

How is the spoil material analyzed?

Knowledge of the characteristics of the soils and overburden prior to mining and the techniques used to distribute the spoils on the site during mining will help the soils scientist make a preliminary analysis of the spoils. Field observations, and a sampling and lab-testing program, should also be undertaken.

Discussion:

If one knows what the geologic profile of the overburden was prior to mining and how the material was deposited and regraded, one can predict what materials will show up in the spoils material. Of course, this material will now be mixed in complex ways and classification will be difficult, but a preliminary analysis may be done by on-site inspection. For example, the soils scientist can use a standard soil survey practice of traversing the area, exposing pits in the spoils material, and observing the nature of existing profiles.

In one situation, a soils scientist observed an interbedding of shale and sandstone in the overburden profile on a coal-mine site. The shales were segregated by color—darker gray shales were often the unoxidized material from the lowest part of the overburden profile and were likely to be a problem material because of rapid dispersion of the clay and high sodium levels. The lighter colored shales, in contrast, had undergone more leaching and thus were a more amendable material. The sandstone and residual coal in the spoil material could also be visually categorized.

In this way, the spoils analysis was aided by noting the color and texture of the materials in the dump and relating this information back to the specialist's knowledge of the type of material in the soils and overburden.

Exception: In some cases, mixing the spoils will result in a material that is essentially

all one color. In addition, caution should be exercised when relying on visual observation alone. In some cases, materials that look similar will exhibit widely different chemical characteristics when tested in the lab.

It is important to set up a standard method of sampling, testing, and interpretation so that the samples can be accurately compared to one another.

What sampling intensity and frequency are necessary?

Sampling intensity and frequency depend on legal requirements, the plant-rooting depths of the vegetation planned for the site, hydrologic considerations, the intensity of sampling used during premining analysis of soils and overburden, monitoring plans for the site, and professional judgment that a representative characterization has been made.

Discussion:

Legal requirements may dictate both intensity of sampling, including depth and spacing, and how often the spoils must be tested over time. If legal requirements do not apply, samples should be taken at least to the depth that the plant roots will reach. Hydrologic considerations will also influence sampling depths, and therefore the hydrologist should assist in determining this factor.

When relating spoils testing intensities to the intensity of sampling soils and overburden prior to mining, it is important to remember that if the sampling was widely spaced during premining analysis, inhibitory zones in the material may have been undetected. In such a case, a more intense sampling of the spoils may be necessary to determine if there are problem materials that must be treated.

The soils scientist should also decide if a spoils testing program should be set up to analyze and monitor the material for changes over time, based on his knowledge of the likelihood of a long-term problem at the site.

What should be done with the spoils samples once they are collected?

The soils scientist, hydrologist, and vegetation specialist can outline what parameters should be tested for, based on their knowledge of the characteristics of the site prior to mining and the type of vegetation and end use planned for it.

Discussion:

Chemical and physical problems detected prior to mining should be tested again to determine whether the problems were mitigated as the mineral was mined. In addition, consult with a hydrologist to determine if specific hydrologic tests are needed.

How are the results of spoils analysis used?

The results should be used to set up an appropriate spoils treatment program, to determine what vegetative species will best adapt to the site, and to outline what management practices are needed to maintain the established productivity and to protect the site from erosion. Of course, requirements stipulated by law in this regard must also be consulted.

Discussion:

Although precise interpretations of spoils analysis tests are difficult, general estimates of conditions existing in the spoils material are possible. Based on these estimations, revegetation plans may have to be altered, and certain chemical or physical amendments may be recommended to ameliorate unfavorable conditions. In addition, the soils scientist might recommend that certain problem materials either be removed or buried at a greater depth. Such recommendations often require an alteration of the reclamation plan.

Additional Information:

For more information on analysis of spoils, refer to "Laboratory Methods Recommended for Chemical Analysis of Mined-Land Spoils and Overburden in the Western United States," U.S. Dep. of Agric., Agriculture Handbook 525.

Also refer to USDA-Soil Conservation Service Technical Guides for appropriate soil management practices. These guides are available at local Soil Conservation Service offices.

Chapter 6
TREATING SPOILS PROBLEMS

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Based on the results of spoils analysis and on-site observations, the soils scientist may determine that the spoils must be treated in some way prior to planting. Chemical, physical, and biological problems, and some recommended solutions, are discussed in this chapter.

Before prescribing any treatment, however, the soils scientist should realize that conditions on the site must be both within the physiological tolerances of the plants and suitable to the planned land use. In most cases, the goal will be to return the site to a beneficial use—not merely to get plant materials to grow. As part of this process, new soils will be built from the spoils.

Because some species can tolerate less-than-optimum conditions, treatments are not always justified; only when the problem is severe enough to prevent permanent establishment of vegetative cover should special treatments be used. It should also be noted that rehabilitation is achieved in phases, and the vegetation treatment in progress may be a successional stage in the planned process.

CHEMICAL PROBLEMS/TREATMENTS

Included in this section is a discussion of problems and recommended treatments for excessive acidity, salt and sodium concentrations, and trace metals.

When are treatments for excessive acidity or alkalinity necessary?

Whether or not the site requires treatments to correct an acid or alkaline condition depends on the spoils' characteristics, as indicated by analysis, and the capability of the desired plant species to adapt to these conditions.

Discussion:

Chemical properties of spoil material are a major consideration for vegetation of disturbed sites because acid and alkaline spoil conditions frequently occur in the West. Acid-mine problems are most often associated with ore production from geologic materials containing sulfide minerals, such as uranium, lead, copper, cobalt, iron, chromium, platinum, and other metals. Alkaline spoils are also common to western mining operations. Alkaline problem areas are generally found in arid and semiarid regions where precipitation is insufficient to leach out salts, although they also occur in poorly drained, low-lying areas and high water-table areas due to slow leaching.

The revegetation of such mine sites may require physical and chemical treatments prior to planting as well as selection of adapted plant species. The role of spoil chemistry cannot be overemphasized for successful reclamation of disturbed mine sites. The soils and vegetation specialists must determine the extent of the spoils problems, such as dispersion, metal toxicities, insufficient amounts of essential minerals, and extremes in pH (fig. 22). With this information, it is then possible to formulate soil amendments that will help to ameliorate toxic and other undesired conditions that retard or eliminate plant growth. The following discussion illustrates the importance of understanding the basic soil-spoil environment affecting plant growth, and can serve as an introductory guideline for understanding chemical problems associated with spoil materials.

The parent material of the spoils controls, to a large extent, the chemical properties of the spoil. The productivity of the spoil may also be altered by the action of climate and vegetation. Chemical properties modify the spoil's physical

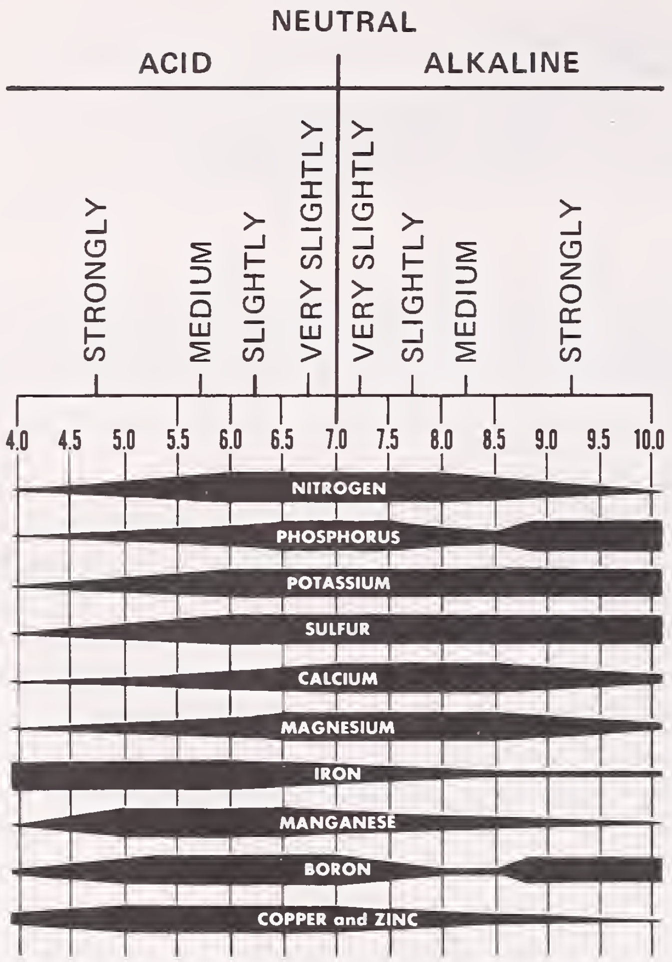

Figure 22. How pH affects nutrient availability. (Texas Agricultural Extension Service)

properties, and the chemical nature of the spoil controls the supply and availability of mineral nutrients for the growth of plants and the relative acidity or alkalinity of the medium.

To determine whether a spoil is acidic or alkaline, soil pH tests can be run, and the results related to those commonly found on undisturbed sites. Undisturbed soils vary widely in pH. The extreme range which might be recorded could be from 3 to 10. Most undisturbed soils fall in the range from 4 to 8.3; most productive soils from 5.5 to 8.3, although some sensitive plants may show chlorosis (yellowing of leaves) above pH 7.5.

• **Acidic spoils.** Spoils on the acid end of the scale—even the ones at pH 3—produce some kinds of plants. At the extremes of acidity, however, production is low, and the number of species is somewhat restricted. In fact, the species contained in a plant community are determined as much by acidity as by any other single soil/spoil property.

The influence of acidity on plant growth is not generally thought to be associated with hydrogen ions as such, but to the influence of acidity on the solubility and plant availability of nutrient elements, such as iron, aluminum, manganese, and phosphorus. Thus, poor growth at very low pH may not be due to excessive hydrogen-ion concentrations, but to an excess and toxicity of iron and aluminum, which are very soluble at such acidity levels, and to the lack of phosphorus, which is insoluble under such conditions.

• **Alkaline spoils.** Spoils in arid areas will tend to be basic or alkaline and to remain so because of the lack of water needed to leach the basic ions after replacement by hydrogen and the presence of a reserve of basic ions (lime). Plant growth on alkaline spoils is directly related to the presence of hydroxyl ions as well as the solubility and availability of mineral elements.

Colloids play an important role in alkaline soils and spoils. A colloid is an extremely small particle of soil with special properties that are not possessed by larger particles, such as sand and silt. Soil colloids have negative charges and act as large, multicharged, insoluble anions. The negative charges of the soil colloids repel the negative charges on the anionic particles, and they are lost with percolating water. Cations are positively charged and hence will be held by the negatively charged soil colloid. Because of selective adsorption, some elements, such as sulfur and nitrogen, which are held as sulfate (SO_4) and nitrate (NO_3) anions, may be leached from the soil and become limiting to plant growth. Other elements, such as potassium, magnesium, and calcium, are held by the colloid and are not as readily leached from the soil. Plants depend upon this soluble fraction for their mineral nutrition. Some mineral nutrients, notably nitrate nitrogen, are rapidly leached from the root zone. Other elements, such as calcium, magnesium, potassium, and sodium, are also soluble but are not readily leached because they are held by the soil colloid. Soils vary in their capacity to hold nutrient elements due to two factors: (1) soils vary in their colloid content (clay and organic matter), and (2) the various kinds of clay and organic matter differ in their exchange capacity.

The kinds of cations which are held on the surface of the colloid determine the soil/spoil structural status and the relative acidity or

alkalinity of the soil/spoil system. If hydrogen ions are present in the amount of 10 percent or more of the total exchange capacity, the soil will be acid (pH less than 7). If calcium ions exceed all others and there is little, if any, adsorbed hydrogen ($H+$), the soil will be alkaline but will not be alkaline enough to adversely affect most plants (pH will not exceed 8.3). If sodium ions predominate, the soil would be distinctly alkaline (pH greater than 8.5)—often so alkaline that most plant growth is not possible.

Flocculation and dispersion of colloids have practical implications in the use of soils/spoils. When a soil is under influence of soluble salts in excess of the amount which can be adsorbed on the colloid, the colloid will be flocculated regardless of the kind of ion which is present, including sodium. If a soil with an excess of sodium chloride is leached, water and dissolved salts will be removed until the excess of salt is dissipated. At this time, the colloid will begin to disperse and will seal up so tightly that no more water will move through the soil. Soil colloids also flocculate and disperse in the same manner, with the flocculated condition being the normal and desirable condition and the dispersed form somewhat uncommon and definitely undesirable. Dispersion occurs when sodium ions, and to a lesser degree potassium ions, predominate on the soil colloid.

High salt concentrations reduce the uptake of water by plants, retard their growth, or may reduce the uptake of nutrients by plants. High concentrations of some salts, such as boron, can even be toxic to plants. The amount of soluble salts that may impair plant growth depends on the type of salts, the type of soil/spoil, and the species of plants; however, arbitrary guidelines have been established by the U.S. Salinity Lab staff. A soil/spoil is considered saline if the electrical conductivity (EC) of a saturated extract is 4 mmho/cm.

Sodic spoils are a specific type of salt-affected spoil. They occur when sodium ions are so dominant in the spoils that they may adversely affect plant growth. The percentage of sodium ions adsorbed on the cation exchange sites of a spoil is called the exchangeable sodium percentage (ESP), and if this figure exceeds 10, the spoils may be sodic.

Another lab measurement of a sodic spoil is its sodium adsorption ratio (SAR). If the SAR exceeds 10, the spoils may be sodic.

Sodic spoils are highly alkaline. They may be impermeable to water and crust when dry. Any spoil with a pH above 8.5 should be suspected of containing sodium. A spoil dominated by calcium seldom will exceed pH 8.3. A spoil having a pH of 10 will generally not grow plants, will probably be dispersed, and will be extremely difficult to manage.

How are acidic spoils treated?

In much of the West, acid conditions result from the oxidation of sulfide minerals, and these materials must be treated if rehabilitation is to be a success. Generally this treatment involves determining what pH level can be tolerated by the desired plant species and then deciding if a physical and/or chemical treatment will be necessary. Physical treatments limit exposure of the spoil material to oxidation. The most common chemical treatment is the addition of lime in some form to neutralize the acidic condition.

Discussion:

Some plant species, such as lodgepole pine and subalpine fir, will tolerate somewhat acidic conditions. Vegetation specialists can provide information on pH levels that can be tolerated by various plant species.

Before undertaking a treatment program on mined spoils, it is recommended that these treatments be tested on field plots because spoils-treatment requirements may differ substantially from those rates recommended for acidic agricultural soils. Test plots, using plants as indicators of treatment success, will more accurately determine the type and amount of treatment that is effective.

Physical treatments to correct acidic conditions can include the addition of organic matter to the spoil. Topsoiling also adds organic matter as well as burying spoils deeper, thereby further reducing oxidation.

Whenever acid-producing spoils are ripped or harrowed, lime must be applied to the depth of the soil disturbance. Such application will maintain a neutral spoil as oxidation takes place. Because acid spoils and acid drainage water both result from the oxidation of minerals (such as sulfides) located on or near the surface, the stability of surface materials is also a major in-

fluence on acid production. Thus, control of erosion merits special consideration in reducing high concentrations of acids in the spoils. Establishing a quick growing vegetation on the site is probably the best way to control erosion and slow acid production.

Lime can be added to acidic spoils in these forms:

- Ground limestone, or calcium carbonate.
- Burnt lime, or calcium oxide.
- Hydrated lime, or calcium hydroxide.
- Lime residue from sugar-beet processing.

Several considerations are involved in determining what type of lime to use. First, ground limestone is very insoluble in water but quite soluble in an acid. Therefore, if a long-range effect is desired, use agricultural limestone. Ground limestone is most effective when it is ground into various particle sizes and mixed at least 10 inches deep into the spoils. Second, calcium oxide and calcium hydroxide are forms of lime which are very soluble in water. These forms can be used for an immediate effect but would not be long lasting. Burnt lime and hydrated lime may temporarily raise soil pH to values of 8.5-9. After application of these forms of lime, time should be allowed for the pH to stabilize before applying fertilizer.

To determine the amount of lime that must be added to the spoils, the soils scientist must estimate both the amount of acid that currently exists and the amount that will be produced in the mined spoils over a given time. Two methods are used to make this determination:

- The first method is to determine the acidity in the soil-buffer system. Soil-buffer acidity is composed of free hydrogen ions and hydrogen ions that arise from hydration of certain ions, such as aluminum and ferric ions. In agriculture, lime requirements are generally based on the buffering capacity of a soil.
- The second method takes into consideration the oxidation of pyrites—metallic sulfides. This aspect of acid production is particularly relevant to heavy metal spoils because most of the acid found on these sites is produced by this phenomenon.

The rate of oxidation of pyritic material is related to its form and to the particle size of the sulfide material in which it is contained; the finer the material, the more rapid the oxidation. Thus, determining the extent of the acid problem involves concentrating on the material that will contribute to sulfuric-acid production—namely, the small clay-size and fine-sand to clay-size particles—rather than the larger material.

By measuring the sulfide or reduced sulfur content of these fine materials and the fraction of the large material with potential for being weathered down to that size, one can arrive at an estimation of oxidation rates and the amount of lime that will be required over time to neutralize the acid as it forms. The microbiological activity in the spoil should also be considered because oxidation is significantly accelerated by microbiological action.

As a specific example, on the Blackbird, a copper-cobalt mine in Idaho, the buffer lime requirement in the spoil material was estimated at about 2 tons/acre. But when the sulfide oxidation in the existing small particulate matter and the material which might be weathered to a small size over about 20 years time were measured, the lime requirement increased to an average of 20 tons/acre/surface ft of soil depth. Because lime materials, in particular calcium carbonate, do not readily move up and down in the spoil, they must be applied to the depth to be treated. In the example at the Blackbird, if the soils scientist wanted to treat 2 ft of surface spoils, he would have applied 40 tons to the acre rather than 20 tons.

It is estimated that this treatment will last at least 10 years, and during this time, natural regeneration of native plants should take place. For example, lodgepole pine will replace the grasses previously used to stabilize the spoils, the physical and chemical characteristics of the spoils will improve, and acid production will decrease as less surface is exposed to oxidation and oxygen concentrations in the root zone are reduced.

In addition to correcting a low pH, lime will:

- Improve the physical condition of the spoil.
- Add calcium to the spoil.
- Accelerate decomposition of organic matter, providing for release of nitrogen.
- Increase fertilizer efficiency.
- Increase nutrient availability.
- Decrease toxicity of aluminum and ferric ions.

Exception: In rare cases, usually on aban-

doned sites when the source producing the acid cannot be determined, it may not be feasible to neutralize the site chemically. Isolating the area may be the only effective treatment. This might include eliminating all possible water from the site, to prevent more acid production, and capping the area with rock. Capping will reduce surface erosion from both wind and water. Further attempts at revegetation may have to be dismissed in these cases; however, a well-planned operation should not leave such a site.

How are alkaline spoils treated?

Choosing salt-tolerant plant species and applying various physical treatments are effective. Chemical amendments are generally reserved for sodic spoils.

Discussion:

Salt-tolerant species, especially various types of grasses, should be identified and considered for revegetation.

Physical treatments for salt-affected spoils include leaching excess soluble salts through irrigation and adding good quality topsoil and organic matter to the spoils to improve spoil aggregation and structure and to increase the fertility of the spoils. Mulching to aid seedling establishment and seeding only when the spoils are well supplied with water are also recommended. Deep tillage should be avoided in high water-table areas or areas where it may cause salt movement up toward the surface. Disking or subsoiling to improve soil structure and aggregation is a viable method elsewhere.

If physical treatments do not alleviate a sodic problem, chemical treatments can be applied. The two most often used chemical amendment types are:

1. Soluble calcium salts. Calcium chloride and calcium sulfate, also known as gypsum.
2. Acids or acid-formers. Sulfur, sulfuric acid, iron sulfate, aluminum sulfate, and lime sulfur.

Soluble calcium salts may be used universally on sodic spoils; these salts replace sodium ions with calcium ions and increase permeability. Calcium chloride is more soluble than gypsum and has a more immediate effect; gypsum is less soluble and less expensive.

Sulfur and sulfuric acid are useful to treat limey spoils. Acids added to spoils containing no alkaline earth carbonates may make the spoils excessively acidic, however. Rely on spoils analysis for specific types and amounts of amendments to use.

Exception: If a sodium problem exists on a site that has no drainage, leaching may not occur and the treatments prescribed for sodic spoils may not be effective.

Additional Information:

For more information on treating sodic soils with gypsum, a summary of a series of studies performed by Bio-Search and Development Co. for the Old West Regional Commission is provided in this chapter.

How are toxic element problems identified and treated?

Poor growth at very low pH may not be due to excessive hydrogen-ion concentrations, but to an excess and toxicity of iron and aluminum, which are very soluble at such acidity levels, and to the lack of phosphorus, which is insoluble under such conditions. Through testing, the soils scientist must determine if toxic elements are present in amounts that will adversely affect plant growth or the food chain. Treatments are essentially the same as those applied to acid spoils.

Discussion:

As noted before, some plant species have a metal tolerance, and these plants should be identified and used when a seed or plant source is available. If, however, the spoils are identified as toxic to plants (for example, the spoils have a high concentration of aluminum or copper), the pH must be controlled on these spoils so that the toxic metals do not go into solution and become taken up by the plants. Potential toxicity to animals grazing plants containing metals such as boron, molybdenum, and selenium must also be considered.

Why is the addition of organic matter an important treatment?

Organic matter builds and maintains fertile soil from mined spoils. It will improve the spoils both chemically and physically by improving

cation exchange capacity, aggregation, tilth, and water-use efficiency. Organic matter adds essential nutrients through the processes of biological decomposition, oxidation, and reduction.

Discussion:

To accumulate organic matter in spoils, it is necessary to produce high levels of biomass. This is done, first, through careful site preparation. For example, it has been shown that ripping increases biomass production (table 12). Chemical fertilization is also necessary to get good plant growth and deep roots. Deep rooting tends to improve spoil structure, aggregation, and water movement through the spoils. As these plants die, they contribute an appreciable

Table 12. — *Effects of ripping on biomass production*[1]

	In ripping marks	Between ripping marks
Shoot biomass	4,000 lb/acre surface biomass	2,000 lb/acre surface biomass
Root biomass	20,000 lb/acre root biomass	10,000 lb/acre root biomass

[1] Information supplied by B. Z. Richardson

TREATING SODIC SOILS WITH GYPSUM

A series of studies performed by Bio-Search and Development Company for Old West Regional Commission has provided some useful principles in treating sodic soils with gypsum:

1. The ammonical radicals (NH_4) of ammonium nitrate and ammonium sulfate fertilizers are superior to the calcium (Ca) cation of gypsum ($CaSO_4$) in removing sodium (Na) from sodic soils. Anhydrous ammonia (NH_3) or urea would not be suitable substitutes, however, due largely to lack of anions in leaching of the sodium.

2. Maximum amendment activity resulted from combinations of gypsum, ammonical fertilizers and calcium chloride ($CaCl_2 \cdot 2H_2O$) of the folowing ratio:

Gypsum	80%
$(NH_4)\ 2SO_4$	10%
$CaCl_2 \cdot 2H_2O$	10%

Such a combination is more than twice as effective as gypsum alone. Early results also indicate that the above combination is superior to gypsum alone in preventing upward migration of sodium from mine spoils into replaced topsoils.

3. Scrubber waste from power plants using limestone ($CaCO_3$) as the scrubber agent is almost as active as gypsum in treating sodic spoils. Although composition of scrubber waste will naturally vary from plant to plant, it is usually composed mainly of $CaCO_3$, $CaSO_4$ and $CaSO_3$. Addition of 10 percent ammonical fertilizers results in good amendment properties and essentially doubles the degree of activity compared with scrubber waste alone.

4. A "Filter Rate" analysis, as developed by Bio-Search, was the single most consistent indicator of amendment action. SAR (sodium adsorption ratio), calcium, sodium, or the Ca/Na ratio are inadequate measurements of amendment activity. "Filter Rate" was also the only one of the above indicators that was significantly correlated with yield of the harvested crops in field and greenhouse studies.

The "Filter Rate" test is performed as follows: Soil is ground to pass a 2 mm sieve. Air dried 0.58 lb lots are weighed, placed in 2-quart plastic containers, and the appropriate amendment-dosage is added, followed by deionized water to give the soil:water ratio desired (generally 1:3). The resultant slurry is mixed until homogeneous and allowed to sit overnight (20 hr). The next morning the slurry is transferred to Buchner funnels and the extract of filtrate collected. The amount of filtrate collected in 100 ml graduates (without suction) after 2 hr is recorded and reported as "filtration rate." The total amount of filtrate collected is also recorded. Time is a big factor in collecting total filtrate—the higher amendment dosages increase soil permeability, and filtration may be complete in 2 to 3 hr, whereas the untreated controls may require 12 to 20 hr of filtration time. Presumably, this method would relate to infiltration rate as measured by more conventional means.

amount of organic matter to the spoils. The surface residues act as a mulch, aiding in water infiltration and erosion control as decomposition takes place. Root residues usually decompose at a slower rate and thus serve as a continuous reservoir of polysaccharides for aggregate stabilization and a reservoir of nutrients for recycling to new plants.

Micro-organisms in the spoil convert these plant residues to elemental nutrients, which stimulates growth in both micro-organisms and plants. Thus, a constant source of energy is supplied by growing plants to soil micro-organisms, which in turn makes nutrients available to plants. This explains why, once organic matter is established in the spoil material, supplements of inorganic nutrients are rarely needed. Early in the process, however, nitrogen fertilization may be necessary because it is the nutrient most needed by micro-organisms in decomposing organic matter. Nitrogen is also the most mobile of the major nutrients and can be readily lost by leaching from rain or snow melt. Micro-organisms may consume more than 20 lb of nitrogen/ton of grass in the decomposition of that grass. Twenty pounds or more of nitrogen/ton of mulch may also be consumed or "tied up" by microbial metabolism as the mulch decomposes. Thus when organic mulches are used, nitrogen fertilization must be increased.

PHYSICAL PROBLEMS/TREATMENTS

Physical problems in the spoils include extremes in texture, lack of or unfavorable structure, and lack of organic matter. Physical treatments can include mulching, mechanical/surface manipulation, and leaching. Counteracting the adverse effects of poor texture and structure by mixing spoils and the addition of organic matter are important because of their influence on infiltration, permeability, drainage, moisture storage, aeration, plasticity, compaction, ease of root penetration, crusting, and retention of plant nutrients. The importance of organic matter has been discussed in some detail earlier in this chapter. Figures 23-31 illustrate one successful site-preparation sequence.

What is meant by texture and structure and why are they important?

Texture is the relative proportions by weight of sand, silt, and clay. Structure is the aggregation of primary particles of sand, silt, and clay into compound parts or clusters. The correct texture and structure of spoils are important in providing a suitable plant-growing medium.

Discussion:

Structure is not as important a characteristic

Figures 23-31. Site preparation sequence used at Decker Coal Mine, Decker, Mont. (Dwight Layton, Decker Coal Mine)

Figure 23. Ripping spoils.

Figure 24. Laying down topsoil.

Figure 25. Ripping topsoil.

Figure 26. Disking.

Figure 27. Fertilizing.

Figure 28. Harrowing.

Figure 29. Seeding.

Figure 30. Hydromulching.

Figure 31. Results.

as is texture, but it does influence the effects of texture in terms of moisture/aeration relations, available plant nutrients, micro-organism distribution, moisture infiltration, and permeability.

Texture is important because this property influences permeability and the amount of water available to plants. Texture must be considered early in the rehabilitation process because it is a permanent condition and influences all subsequent reclamation activities on the site.

Clays, for example, have a relatively high water-retention capacity, but their permeability is low and, if they also contain appreciable quantities of exchangeable sodium, the material becomes essentially impermeable. By comparison, sand has a high permeability but low water-retention capacity, and this can lead to a droughty condition.

How can a suitable texture be achieved?

Placing medium-textured material—not extremely high in either clay or sand—in the plant-growth zone is ideal. But if these kinds of materials are not available, mixing prescribed amounts of favorable soil textural types can artificially produce the desired texture. The addition of organic matter and proper tillage operations can counteract the adverse effects of poor texture by improving moisture/aeration relationships.

Discussion:

When it is not possible to replace topsoil on the disturbed site and when a suitable substitute from the overburden strata is not available, the return material must be treated sufficiently to support plant growth. Treatments to reduce compaction are usually necessary. For example, ripping and harrowing the spoils during seedbed preparation will reduce compaction and increase the infiltration capacity of the spoil. Contour planting, fertilizing, mulching, and cultivating will aid in plant establishment, thus encouraging the production of organic matter. As discussed earlier, organic matter plays a crucial role in improving the physical and chemical characteristics of soils and spoils.

In a greenhouse study on high-sodic, bentonite spoils, vermiculite and sawdust were effective amendments. They reduced cracking in the spoils, and the sawdust added organic matter at the same time. It appears that these materials act as a binder and limit the stretching characteristics of the spoils.

BIOLOGICAL PROBLEMS/TREATMENTS

Because ultimate reclamation goals aim at returning the mined site to some type of productive use, the ability of the site to sustain life without endangering its stability becomes an important aspect of rehabilitation. In addition, many organisms, especially micro-organisms, are essential to the soil forming process. Both macro- and micro-organisms are included in this discussion.

What site conditions are necessary to support macro-organisms?

Different animals require different types of habitat. For example, animals respond in different ways to all these soil conditions: elevation, geomorphology, slope aspect and slope steepness, soil temperature and moisture, rockiness, soil pH, conductivity, macro- and micronutrients, and compaction. Thus the type of animal life desired will influence how the site should be managed.

Discussion:

Several general examples of preferred habitats of various animals from a soils perspective follow:

- Deer. Deer prefer north-facing slopes in the summer, south-facing slopes in the winter. Soil toxicity is important—for example, high concentrations of copper in plants can be toxic to deer. Deer often depend on salts found in plants and soils on valley bottoms.
- Cattle. For uniform utilization of the area, slopes should be less than 20 percent.
- Burrowing animals. Burrowing animals cause soil texture on burrow mounds to become finer. They will reduce compaction by their burrowing. In studying pocket mice, a type of burrowing animal, it was found that they inhabit less densely vegetated sites in greater numbers than they inhabit densely vegetated areas. Phosphorus and sulfur levels increased in soils inhabited by these animals; calcium and magnesium levels decreased.
- Birds. With the exception of waterfowl, as plant cover increases, birds observed on mined

sites generally decrease in numbers. Hawks and owls will inhabit rock outcroppings.

- Bobcats, rabbits, snakes, lizards. These animals prefer rocky areas.

What problems can occur with the introduction of macro-organisms onto a mined site?

In some cases, the introduction of macro-organisms onto the site will lessen the stability of the soil or seriously deplete the vegetation.

Discussion:

Some areas may have such critical characteristics as slope compactability that animals should be restricted or specifically managed to prevent further damage or deterioration of a reclaimed site.

With intense grazing, soil moisture will decrease, and soil temperature and compaction will increase. Burrowing animals may bring harmful substances, such as radioactive, toxic, or salt materials, to the surface.

In addition, if the site is managed for species that prefer bare soils, erosion and sedimentation problems may occur. In general, managing a bare area to accommodate such animals should be considered only if they are an endangered species.

Why is the lack of micro-organisms in the spoils a problem?

Micro-organisms, such as bacteria and fungi, are important in the decomposition of biological materials and the formation and improvement of soil itself. But because most microbial activity occurs in the upper layers of soil, mined spoils whose surfaces consist of deeper layers of geologic material may be void of these organisms.

Discussion:

In their roles as decomposers, micro-organisms reduce plant litter, which lowers fire hazards and perhaps aids in seedling emergence. They are the major contributors to nutrient cycling, releasing to the environment the nutrients that have been fixed into plants or other biological materials. The formation of soil organic matter, or the process of humification, is mediated primarily by micro-organisms. They also indirectly reduce soil bulk density by improving aggregation.

Nutrient cycling, especially nitrogen cycling, is a major contribution of micro-organisms. They also make phosphorus available to plants through phosphorus solubilization.

Thus, it is apparent that unless artificial amendments can be added to the reclaimed site indefinitely, the introduction of micro-organisms is essential to allow a natural system of building and maintaining fertile soil to take over.

Will micro-organisms move onto the site through natural processes?

It is generally thought that eventually micro-organisms will naturally reestablish themselves in mined spoils. How long this takes will be influenced by the spoils' properties, including physical and chemical characteristics and water dynamics, how topsoiling and soil storage was handled during mining, the rate of vegetation establishment, and the rate of natural inoculation of spoils.

Discussion:

As the amount of clay in the spoils increases, micro-organisms living in the spoils decrease. Salinity, acidity, and the presence of significant amounts of heavy metals in the spoils may inhibit microbial activity. Thus the chemical and nutrient status of the spoil must be in balance at a favorable level to allow micro-organisms to establish themselves and function properly. In addition, moisture must be sufficient for the organisms to carry out their activities, even though they can survive on much less water than can plants.

The effects of topsoil storage on microbial activity are not completely agreed upon by researchers, but the general indication is that microbial processes are adversely affected by topsoil storage, especially if long term and in deep piles.

How can micro-organisms be reestablished in soils?

Both natural processes and artifical amendments are known to increase microbial activity.

Discussion:

Activities that will increase microbial activity include:

- Replacing the topsoil on the mined spoils.

Replace the topsoil as soon as possible after it is removed. If it must be stockpiled, shallow, wide piles are recommended over narrow, deep ones, because most micro-organisms function best near the soil surface. An advantage of quick replacement of the topsoil is that some of the seeds and plants transported in the topsoil will grow on the new site rather than losing their viability because of long-term storage.

> Exception: If wind erosion is a problem, then shallow storage of topsoiling may result in the loss of this valuable resource. The topsoil surface should be protected in some way from wind erosion, perhaps through mulching or temporary seeding with a fast establishing grass.

- Natural processes, such as dust blowing on the site from other areas, will reinoculate the site. Root penetration into the spoils and the development of a rhizosphere environment are also thought to perpetuate the growth of micro-organisms.
- Correcting the spoils for acid, salt, or trace element problems will provide a spoil condition conducive to microbial activity.
- Adding nutrients necessary to assure microbial activity is important. In particular, micro-organisms need a sufficient amount of carbon, phosphorus, and nitrogen. Sufficient carbon will be obtained through mulching. Sufficient nitrogen and phosphorus will probably be obtained through fertilization amounts required to establish plant growth.
- Inoculating the site with micro-organisms, such as nitrogen-fixing algae and/or bacteria. Mulching will help inoculate spoils with micro-arthropods.
- Collecting surface material from undisturbed sites and placing this material on the mined spoils to introduce micro-organisms.

How does the soils scientist determine if microbial activity on the spoils has returned to a level found on adjacent undisturbed sites?

Laboratory analysis for microbially related soil activity can be used to compare undisturbed sites with rehabilitated areas. This comparison will help determine if postmining microbial activity is comparable to the premining state. Population numbers by species in rehabilitated and undisturbed areas are very time consuming and expensive to determine and are, therefore, not useful for most monitoring programs.

Discussion:

Lab analysis for microbially related soil enzymatic activity includes dehydrogenase, phosphatease, and urease. Biomass indicators include adenasine triphosphate (ATP), viable counts, and direct microscopic counts.

In one study on a salt-affected coal mine, it appeared that microbial activities on the mined site returned to levels found on adjacent areas about 3 years after revegetation. Nitrogen-fixing micro-organisms, however, were not as well established as other species, thus indicating that long-term nitrogen fertilization may be necessary. In addition, there was a decrease in microbial activity with the depth of the spoils.

Additional Information:

For more information on treating chemical and physical problems in mine spoils, refer to:

"Handbook on Soils," USDA For. Serv., FSH 2509.15. Washington, D.C. (Amended July 1969.)

Chapter 7
SPOILS SURFACING

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As discussed in chapter 2, premining analysis of the soils and overburden predicts if and in what quantity topsoil and subsoil materials should be stockpiled for later placement on the mine spoils. This analysis, along with State and Federal regulations, also determines whether soil should be removed in one or two lifts.

After the mineral is mined, the spoils are shaped and analyzed, indicated treatments are applied, and the spoils are surfaced with the stockpiled soil. If, prior to mining, the soil was removed in two lifts, the second lift is now placed on the spoils, and the first lift is placed on top of the second lift.

To insure immediate and long-term value of the spoils surfacing effort, potential problems must be overcome by appropriate treatments carried out during or after spoils surfacing. For example, if spoils analysis indicated that the quantity of the spoils is less than predicted during premining analysis and that the quantity of topsoil stockpiled will not be sufficient to serve as a plant-growth medium, additional topsoil should be obtained from adjacent sites, if possible, and spread on the surface.

The most important problems threatening the physical integrity and ability of resurfaced spoil to support plant growth are surface erosion and overcompaction of soils and spoils. Upward migration of toxic elements or salts also presents problems in some cases. This chapter will discuss these potential problems in more detail.

SURFACE EROSION

A vital component of spoils surfacing activity is reducing or preventing surface erosion. Steep, bare, unrevegetated spoils are subject to high rates of erosion by both water and wind (fig. 32). The effect of this is to lessen the stability of the site and, just as important, to remove the valuable topsoil resource that has been surfaced on the mined area. As a result, special efforts to prevent surface erosion are warranted, especially considering that repair of erosion damage is one of the most expensive recurring costs on reclaimed sites. In addition, in some situations, State or Federal laws govern the amount of erosion that is acceptable, and thus the site must be monitored for erosion to satisfy these requirements.

What factors increase erosion by water and wind?

Slope steepness, slope length, drainage provided, control structures, lack of vegetation on slopes, and the type of spoils and soils material on the site will affect the amount of wind and water erosion that will occur.

Discussion:

Research has demonstrated that soil losses from erosion on mined sites can be significant. For example, a 1-year-old, newly reseeded mine dump, which was essentially bare of vegetation, was measured for the amount of erosion that occurred from October to the following July. On a south-facing slope of 48 percent, with a slope length of 1,100 ft, the measured loss was 69 tons/acre. Another example: On a north-facing slope with a steepness of 23 percent and a slope length of 330 ft, the loss was 135 tons/acre. Erosion in both examples was mainly due to water.

Erosion from wind can also be significant. For example, in a Western phosphate field, the production of fugitive dust has been estimated at 1/2 lb/ton of material mined. In 1978, the

production of fugitive dust was estimated at 5,250 tons.

The controlling effect of vegetation on erosion was demonstrated when the areas in the preceding examples were measured after the establishment of vegetative cover (fig. 33). In general, after the second or third year of plant growth, reduction in erosion was on the order of about 90 percent. In this particular study, ground cover was estimated at about 70 percent.

In the Eastern United States it has been found that about half of all soil losses occur in the first 6 months after mining. Thus, it appears that erosion rates are highest during dump construction and during the time from final shaping to the establishment of a protective vegetative cover—in the West, typically 1 year.

Soils that contain finer particles and are less compacted obviously will be subject to heavier erosion losses than coarse-textured or compacted material. It has also been found that topsoil is generally a little more stable than is spoil material because of aggregation.

What treatments will reduce erosion by wind and water?

Mulching, surface manipulation, and proper timing of topsoil placement, followed by immediate establishment of vegetation, will reduce erosion rates on mined sites.

Discussion:

Mulching is probably one of the most economical and widely applied methods of controlling erosion because it reduces the impact of raindrops, overland water flow, and wind (fig. 34).

Several kinds of mulches are effective, but straw is probably the most economical and readily available mulch (fig. 35).

Figure 32. Eroding, ungraded spoils are contrasted with graded revegetated spoils at a coal mine site.

Several techniques of surface manipulation are effective:

• Flatter or shorter slopes will aid in erosion control. Also note, however, that State or Federal regulations may dictate slope steepness and length.

• Sediment basins will help to collect material washing off the site.

• If immediate revegetation is not possible, sediment basins constructed at the toe of new waste dumps may be useful in collecting eroding material—if these basins are correctly designed.

• Shallow furrowing on the contour will cut down on erosion losses.

• Pitting and gouging will both control erosion and act as moisture collectors. Because of their dual functions, pitting and gouging are especially useful in dry areas and those areas where vegetation is dependent on snowmelt for moisture. Pits and gouges differ from each other only in size. Pits, also called basins, are approximately 2-1/2 ft deep and may be 8 ft wide by 15 ft long. Gouges, on the other hand, are a series of small pits about 3-6 inches deep, 18 inches wide and 2 ft long. A number of these depressions are made on the site. Pits are generally used on steeper slopes (3:1, for example); gouging is done on less steep slopes.

A variation of gouging is accomplished by using a land imprinting machine. Although the land imprinter was not specifically developed for mined lands, it has been used on bare sites in Arizona to imprint the surface, which, in turn, catches water runoff and holds it in place, rather than allowing it to run down slopes and cause erosion.

• Buffer stripping during mining can also be encouraged, although this is usually not practical from a mining standpoint.

It has been noted that, because topsoil is an

Figure 33. Establishing vegetation on steep slopes aids in erosion control. The above photo shows an erosion control study plot 3 years after vegetation was planted.

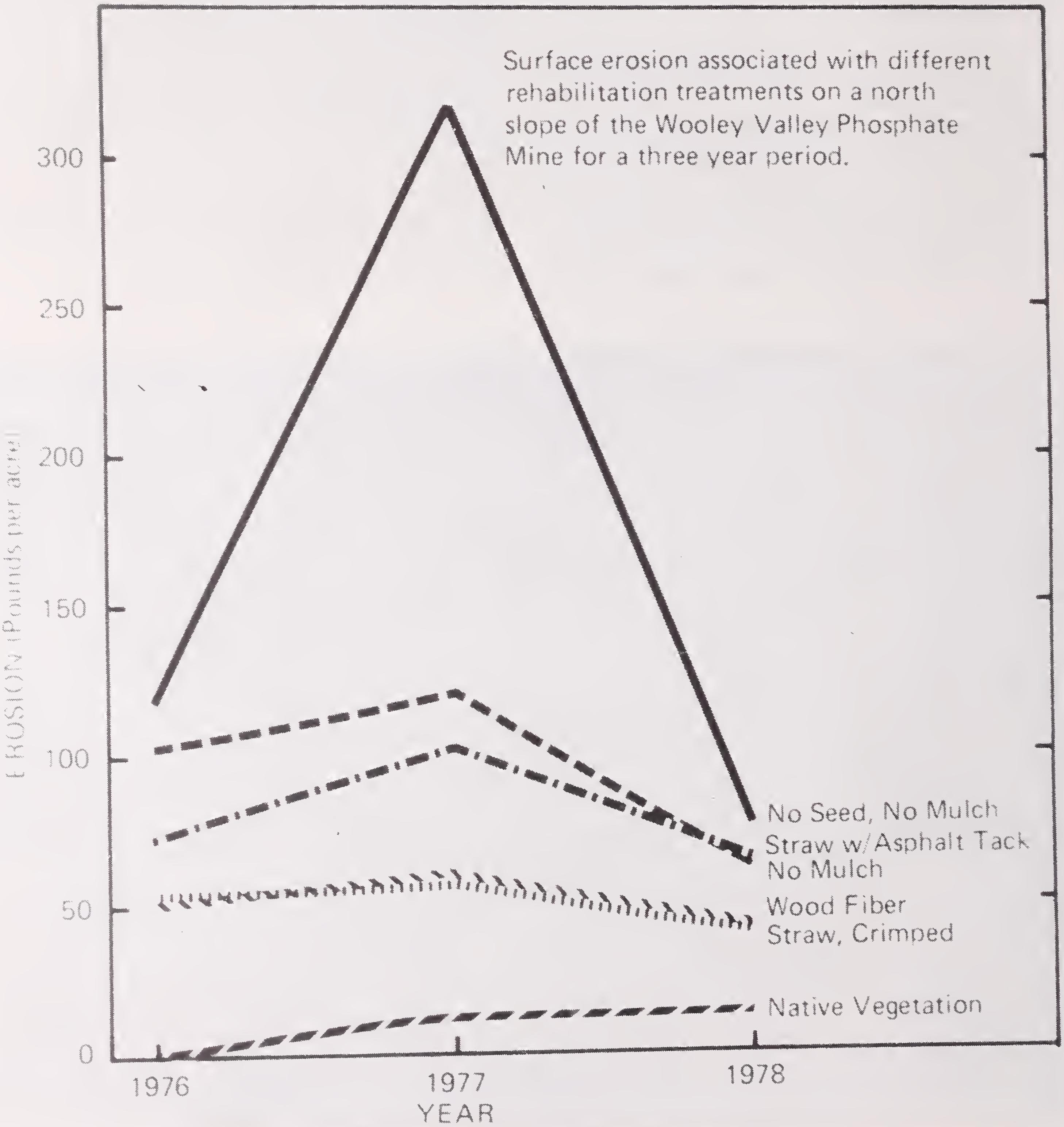

Figure 34. Mulching a revegetated site will reduce soil losses due to surface erosion.

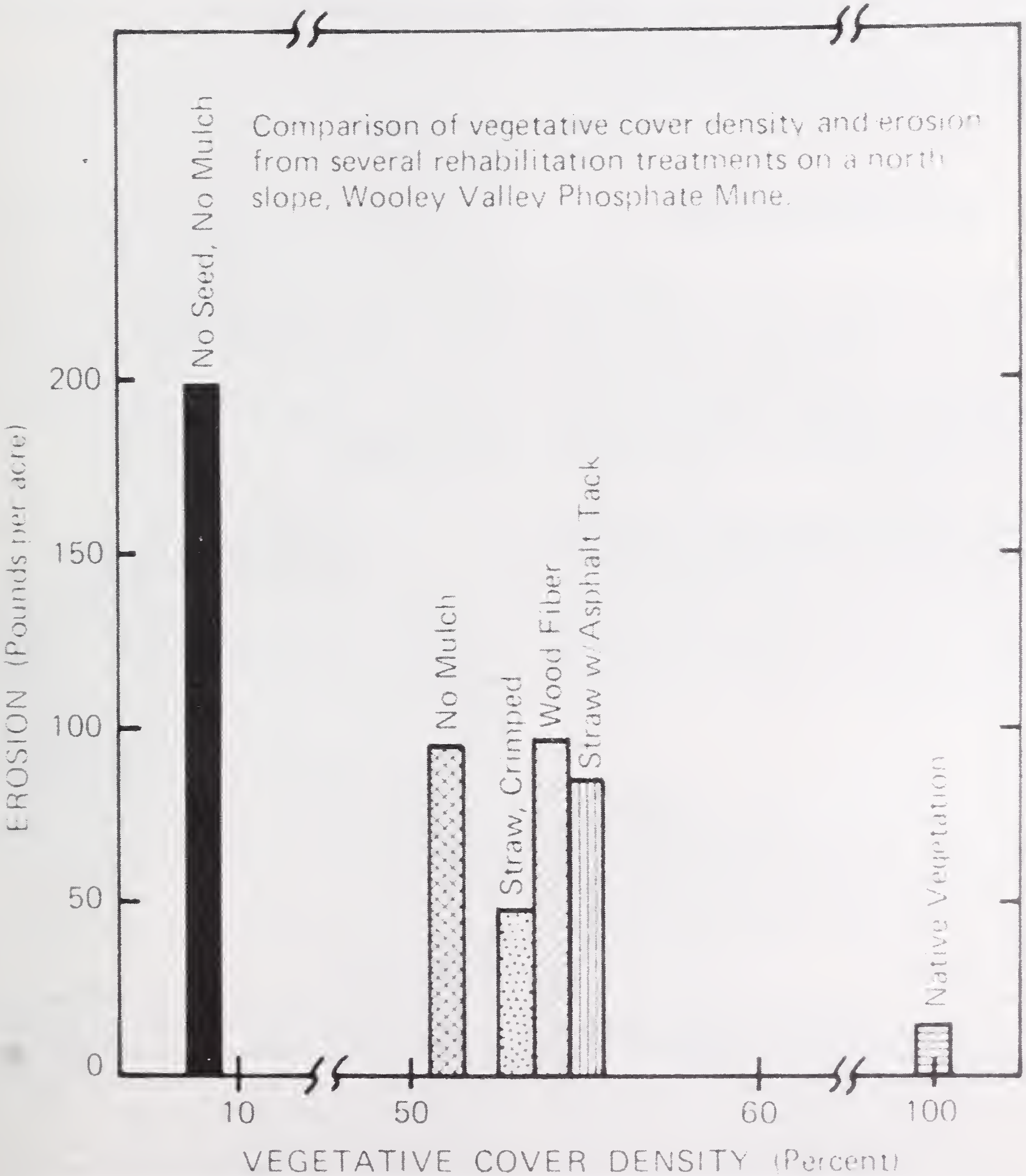

Figure 35. Straw mulch aids in both reducing surface erosion and increasing vegetative cover density.

extremely valuable resource, it should be replaced on the site immediately prior to the best growing season; i.e., just before expected precipitation. In that way, planting can immediately follow topsoil replacement, and a vegetative cover can be quickly established on the site to protect the topsoil.

In those cases where it is feared that excessive erosion will occur during the time it takes for seeds to germinate and establish themselves, the use of bare-root, container-grown, or other transplant stock that will quickly take root and act in erosion control should be considered.

OVERCOMPACTION AND RELATED PROBLEMS

The heavy machinery used to regrade and spread spoils often leaves the material so compacted that root penetration is reduced or blocked. Ripping the spoils can ameliorate overcompaction problems. Tilling the spread topsoil prior to seeding can overcome compaction of the upper soil.

What other problems related to the stripping and respreading process are ameliorated by tillage?

The condition of the smooth, hard interfaces that are often created between the spoil and overspread soil, and the layers of distinctly different subsoil and/or topsoil materials can be improved by tillage.

Discussion:

Topsoil or subsoil spread over a smooth, hard, spoil surface may be subject to slippage or slumping if the hydraulic conductivity of the spoil is sufficiently reduced and if the site is sufficiently sloped. Ripping or deep tillage of the spoil surface during regrading should ameliorate this situation.

What factors are involved in overcompaction, and how can compaction be measured?

The weight, type, and traffic pattern of machinery are, of course, factors. In general, the higher the water content and the finer the texture of the material, the greater will be the potential for overcompaction. Several types of analyses can be used to measure compaction and should be chosen based on the dryness or wetness of the spoils.

Discussion:

For dry materials, bulk density measurements will give an approximate indication of overcompaction, provided textural data on the materials are also available. Bulk density measurements can also be taken on wetter materials. For materials either partially or fully saturated, use of a recording field penetrometer will give a good indication of compaction levels.

Field penetrometers indicate "penetrometer soil strength," a measure that research has linked quite well to the resistance plant roots encounter as they penetrate the soil. This type of measurement will be especially useful to first or second lift soil characterization where the gravel or stone content is low. Wetting a small area of the reclaimed soil and allowing it to drain to field capacity before making penetrometer measurements is the best procedure. Penetrometer soil strength is most logically interpreted by reference to some standard soil water content.

TOXIC ELEMENTS AND SALT MIGRATIONS

Toxic elements can migrate from tailings or spoils into the respread topsoil, rendering it phytotoxic in the extreme case or resulting in plant products that are deleterious to animals or humans when consumed. Upward salt migrations are a special problem where sodic spoils are found. Physical properties—for example, tilth and hydraulic conductivity—of overspread soil deteriorate as a result of such salt migrations.

How may toxic-element and salt migrations be abated?

In suitable circumstances, spreading a layer of gravel or sandstone between the spoils and topsoil may prevent toxic elements from entering the plant-rooting zone. Using such coarse-textured materials between the spoil, which usually exhibits a low hydraulic conductivity, and the soils material will reduce diffusive salt flow. Putting gravel or sandstone on the top of toxic tailings material will break up water flow that

carries salts or toxic elements upward as soil evaporation proceeds.

Discussion:

Generally, the use of these materials is less costly than bringing in additional topsoil. The soils scientist should consult a civil engineer, however, to insure that this interlayer of material will not set up a slippage face, or create a zone where a great deal of lateral water movement will occur.

How are salt migrations predicted?

Figure 36 shows a general model for predicting salt migrations in reclaimed soils. Currently, however, this information is worked out only for research usage and is not yet user-oriented.

Discussion:

In the model shown in figure 36, plant growth is not predicted, but root uptake must be approximately known. This limits the applicability of the model to areas where this knowledge is available. Unsaturated hydraulic conductivity and water-retention capacity of soils and spoils are the key information needed for this type of calculation. Unsaturated hydraulic conductivity measurements are generally limited to research use, however.

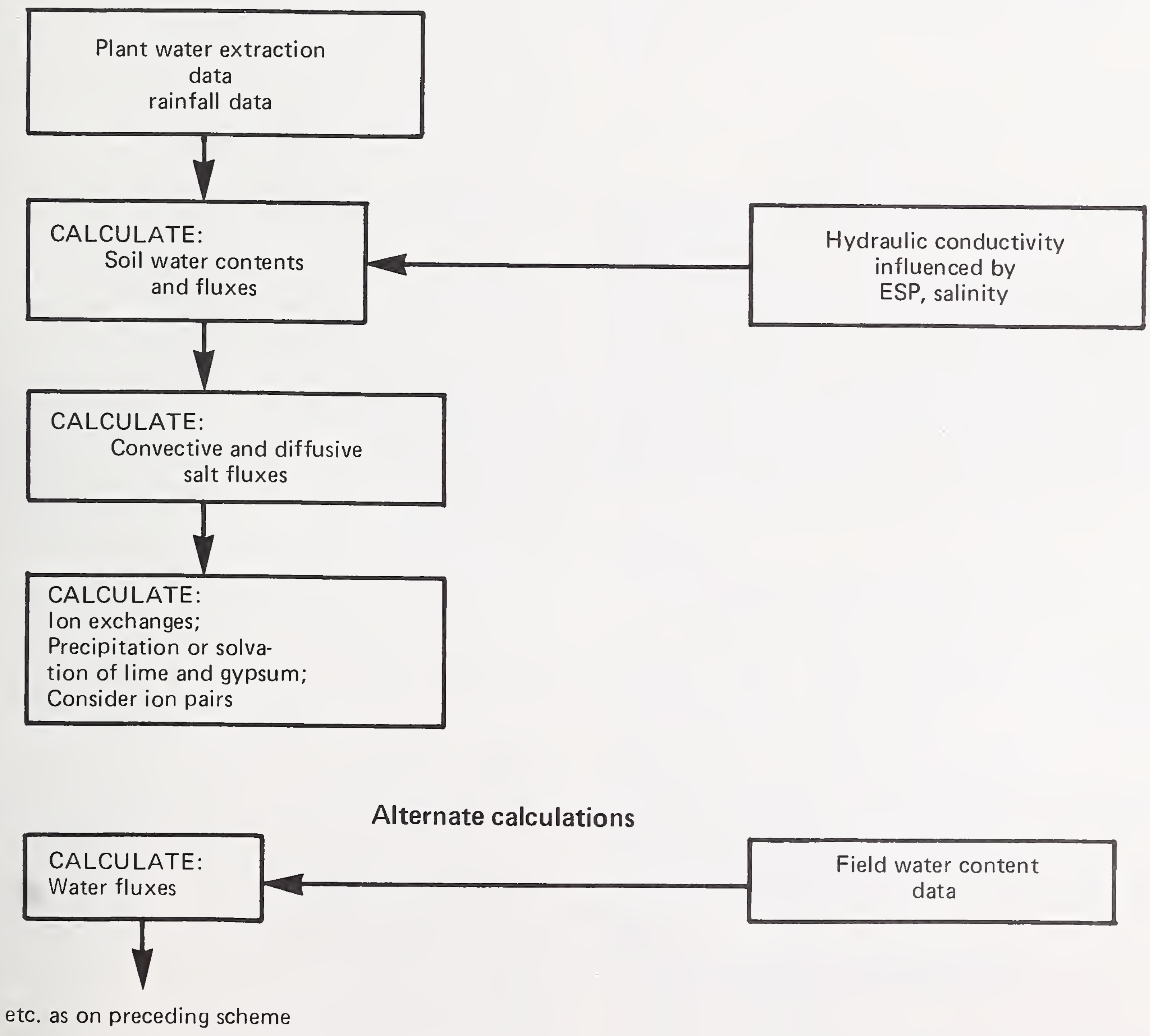

Figure 36. Outline for predicting salt migration in reclaimed soils.

Chapter 8
MONITORING AND RETREATMENT

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Once reclamation work is completed, a period of monitoring follows, during which the success of the reclamation program is evaluated and, if necessary, the site is retreated to correct problems that have surfaced. The object of this postmining monitoring is to assess whether the mining operator has fulfilled his obligation to adequately reclaim the site and thus can be released from his performance bond. Input from a soils scientist will be essential in making these determinations.

Because intensive reclamation of western minelands is relatively recent, postmining monitoring and performance standards remain vague and general. In some cases, such as in coal mining, there are some legal requirements, but these, again, are quite broad. For example, the regulations require that a postmining land-management plan be drawn up, outlining the use or uses to which the land will be put following mining and reclamation, with a discussion of possible alternative uses and their relationship to existing land-management policies. The plans must also include an explanation of how the postmining land use will be achieved, including management and materials required.

In light of these generalities, the land manager will have to rely on available scientific knowledge and his own judgment when setting criteria for releasing the mining operator's performance bond. These standards should be understood and agreed upon by both the land manager and the mining operator prior to mining and should be outlined in the operating plan; however, an allowance for variances as unexpected circumstances occur is also advisable. The standards should include estimated monitoring costs as well as needed personnel.

During the establishment of postmining goals, the land manager and his interdisciplinary team must keep accurate records on the condition of the site prior to mining; the reclamation work done; the potential of the site; and the postmining condition of the site. This process should be recorded carefully in case any part of the mining or reclamation procedure is challenged.

MONITORING

What should the soils scientist monitor during postmining?

Primarily, the soils scientist will monitor and evaluate the plant-soil response to reclamation treatments. He may also be asked to provide information on precipitation and weather variables following reclamation, sediment load, the effect of the area on ground-water quality, salt movement in the soil, erosion rates, and the effects of management practices used on the soil.

Discussion:

A sampling program should be undertaken in order to monitor plant-soil responses to reclamation treatments. The soils scientist will have to determine what sampling intensity to use based on his judgment of the condition of the site, but some research indicates that 1 percent of the total mined area should be sampled.

During sampling, areas where reclamation may have been less successful should be focused on (fig. 37). These include:

- Slopes, in particular, south- and west-facing slopes
- Old road locations
- Former equipment storage sites
- High runoff sites
- Areas with high clay content, or concentrations of sodium or other salts.

What tests should be run on the samples and how should they be interpreted?

The type of testing on the site depends on regulations governing postmining testing, and what problems were identified on the site during mining. The tests should be interpreted against the criteria for reclamation success set up in the operating plan. This comparison will indicate how much the final outcome deviated from the plan, and if this deviation can be tolerated.

Discussion:

If problem areas surfaced during premining soils and overburden analysis or spoils analysis, such conditions should be retested during postmining monitoring to determine if any further retreatment is necessary. In addition, if the soils scientist observed any additional problems on the site, these should be analyzed further.

Interpretations of the tests should be made against the performance standards for the site. Obviously, these can vary, depending on regulations governing the mine operations and the climatic conditions of the site. For example, in some parts of the country, a 70-percent vegetation cover would not be judged adequate; whereas in low rainfall regions, a 20-percent cover is considered adequate. In other words, different levels of "non-reclamation" are tolerated.

RETREATMENT

Based on field observations and the results of the sampling and testing program during monitoring of the site, the soils scientist and land manager may determine that some retreatment is required before the performance bond can be released. Retreatments can include:

- Chemical treatments. Follow-up fertilization or liming.
- Physical treatments. Erosion protection, remulching, fencing.
- Biological treatments. Species manipulation, both of plant and animal organisms.

What refertilization treatments may be necessary?

Based on on-site observations and soils analysis, the site may need to be refertilized for various soil nutrients, in particular, nitrogen and phosphorus. Refertilization is important for two reasons: (1) to support permanent vegetation on

Figure 37. Harsh sites, such as these bentonite spoil ponds, will require special reclamation emphasis and monitoring during postmining.

the site, which will protect the site from erosion, and (2) to increase the biomass growing in and on the soil.

Discussion:

In addition to soils analysis, nutrient deficiencies can also be observed in plants. Nitrogen deficiencies are indicated by yellowish-colored leaves; slow or dwarfed growth; and drying up or firing of leaves, which starts at the bottom of woody plants and proceeds upward or, in grasses, starts at the tip of the bottom leaves and proceeds downward.

Phosphorus deficiencies are noted by purplish leaves, stems, and branches; slow growth and maturity; and small slender plants. Low yields of grains and fruits or no seedheads in grass also indicate phosphorus deficiencies. Potassium deficiencies can be observed in plants showing a mottling, spotting, streaking, and curling of leaves, starting on the lower stems; lower leaves that are scorched or burned on margins and tips; and premature loss of leaves.

Rates for retreating with nitrogen depend on the severity of the nitrogen deficiency as gathered from soils analysis, but in general, 40-80 lb of nitrogen/acre are recommended. Additional nitrogen will be required if organic amendments are added at the same time.

It is important to note that nitrogen deficiencies can be a long-term problem and may require repeated applications of fertilizer. In some cases, the site must be refertilized every 2 years for the first few years, then every 3 or 4 years for several years thereafter. Unfortunately, current research does not indicate in what time span nitrogen refertilization will no longer be necessary. Thus, the cost of refertilization over a long term must be balanced against the cost of the program. If costs are prohibitive, plants adapted to low ntirogen, such as woody species, are recommended. This approach is particularly useful in certain dry climates where fertilizer does not stay in the soil long enough to have a lasting effect. Another technique is to supply the soil with more organic matter because organic matter aids in holding available nutrients. Encouragement of legumes or free-living, nitrogen-fixing microbes reduces or eliminates the need for long-term refertilization.

Regarding phosphorus, 50 lb/acre of triple-superphosphate are sometimes recommended, but on moderately sodic soils, where the SAR is about 12, this amount may have to be increased to about 75 lb/acre. Phosphorus refertilization is minimal—one repeat application is generally sufficient on soils where tests indicate a phosphorus deficiency.

When is repeat liming necessary?

If postmining soils tests indicate an acid problem, a repeat application of lime may be necessary.

Discussion:

Hot spots can sometimes be found on the reclaimed surface after mining, usually caused by an acid reaction in the materials. In the case of coal, regulations state that any material that might spontaneously catch fire be buried by at least 4 ft of material. If fire combustion is not a problem, reliming with calcium carbonate to meet the total lime requirement as determined by testing should provide protection against reoccurrence of acid conditions (see chapter 6).

Additional Information:

For more information on liming, refer to chapter 6.

What physical retreatments should be considered?

Physical retreatments of the site might include repairs to badly eroding areas, remulching on problem areas, fencing, and water and range improvements.

Discussion:

It is recommended that whenever possible, heavy equipment be kept off the site and erosion repairs done by hand, especially if the area involved is relatively small.

Mulching is one way to minimize physical problems, such as gully or sheet erosion, if the size of the gullying system or the sheet erosion is not too large. If a large area is involved, more extensive treatments might be required. Such large gullies are indicators of poor surface hydrology designs in reformed land; these should be corrected before revegetation begins. The mulch should be crimped into the soil.

Fencing (fig. 38) and water and range im-

Figure 38. Fencing may be necessary to protect fragile areas until vegetation is established and soils are stable.

provements are necessary in order to insure the plant and soil stability of the area during the postmining period. For example, because the vegetation on a reclaimed site is often more palatable than vegetation growing on adjacent areas, it may have to be protected from livestock and wildlife until it is firmly established. In addition, roads built during the mining activity will make the area more accessible to human traffic, and thus fencing the area from such traffic compaction may be necessary in order to protect the site.

Additional Information:

For more information on making hand repairs of small gully systems, blowouts, or problem areas, refer to:

"Watershed Structural Measures Handbook," USDA, For. Serv., Handb. 2534. December 1958.

"Land Treatment Measures Handbook," USDA, For. Serv., Handb. 2533. February 1959.

What biological retreatments should be considered?

Biological retreatments might include species manipulation to improve the soil's characteristics, addition of mycorrhizal spores and micro-organisms to the soil, and protection of the site from macro-organisms.

Discussion

The following treatments are only a few ways in which vegetation can be used to improve soil quality:

- Use of green manure. For example, if Russian thistle has invaded the area, it can be used as a green manure crop if it is turned under while still small, and the area reseeded with another species. This is useful in reseeding and repairing small (2-5 acre) areas.
- Interseeding to provide more ground cover and increase species diversity. If possible, it is recommended that hand-held or small machine-operated equipment be used to avoid disturbing the site as much as possible.

Before mycorrhizal spores and micro-organisms are added to the soil, the site should be tested to find whether or not mycorrhizal spores and micro-organisms already exist on the site. For example, mycorrhizal spores are very intolerant of prolonged dry conditions or prolonged very wet conditions, and if the topsoil had been stockpiled for a long time, many mycorrhizal species may have been lost in the soil mass. If these organisms were sampled for in premining stages, the soils scientist can use this figure to make a postmining comparison. Then, if testing indicates a problem, it is important to reinoculate the site using viable spore material. Likewise, other micro-organisms, such as termites, play a role in the refertilization process but may have disappeared during mining and resurfacing activities.

Some macro-organisms are harmful to the site and may have to be removed. For example, small rodents or ants may cause problems on spoils where toxic materials are buried below the surface. These burrowing animals may bring this material up to the surface in the course of their digging. They may also destroy some of the vegetation.

Additional Information:

Refer to the "User Guide to Vegetation" (USDA, For. Serv. Gen. Tech. Rep. INT-64) for more information on topics covered in this chapter, including reinoculation of micro-organisms, refertilization, fencing, and interseeding.

APPENDIX A

GLOSSARY

Acidic soil: A soil containing a preponderance of hydrogen ions, often occurring when sulfide minerals are oxidized. Values below pH 7 indicate an acidic soil.

Adsorption: Adsorption is the increased concentration of molecules or ions at a surface, including exchangeable cations and anions on soil particles.

Alkaline soil: Soil with a pH 7, and which contains excessive concentrations of soluble "salts"—ions of calcium, magnesium, potassium, sulfate, chloride, nitrate, boron, and others. (Also see: Sodic soil.)

Aquifer: A geologic formation or structure that transmits water in sufficient quantity to supply the needs for a water development, such as a well. The term "water-bearing" is sometimes used synonymously with "aquifer" when a stratum furnishes water for a specific use. Aquifers are usually saturated sands, gravel, fractured rock, or cavernous and vesicular rock.

Baseline data: Data gathered prior to mining for the purpose of outlining conditions existing on the undisturbed site. Reclamation success is measured against baseline data.

Cation exchange: Cation exchange is the interchange of a cation in solution with another cation on a surface of active material.

Cores: A sample of the subsurface and geologic materials obtained by vertical drilling. The cores are used to evaluate the quality of a mineral; they also show the type of overburden material overlying the ore.

Critical area: An area that should not be disturbed (i.e., mined) because it is deemed extremely difficult or impossible to reclaim.

Dispersed soil: Dispersed soil is soil which has little or no resistance to the slaking action of water. Also, it is soil in which the clay readily forms collodial suspensions.

Dump: Also called fill, backfill, or storage site, a dump is an area where overburden is piled during the mining process, either temporarily or permanently.

Electrical conductivity (EC): A measurement of salinity. A soil is considered saline if the EC of a saturated extract is 4 mmho/cm. (U.S. Salinity Lab Staff)

Environmental Assessment (EA) (Replaced the EAR): An analysis of all actions and their predictable short- and long-term environmental effects, which include physical, biological, economic, and social factors and their interactions. Also, a concise public document required by the regulations for implementing the procedural requirements of the National Environmental Policy Act of 1969 (NEPA).

Environmental Impact Statement (EIS): A document prepared by a Federal agency in which anticipated environmental effects of a planned course of action or development are evaluated, as prescribed by the National Environmental Policy Act of 1969 (NEPA).

Erosion: The group of processes whereby earthy or rock material is worn away, loosened, or dissolved and removed from any part of the earth's surface. It includes the processes of weathering, solution, corrosion, and transportation. Erosion is often classified by the eroding agent (wind, water, wave, or raindrop erosion) and/or by the appearance of the erosion (sheet, rill, or gully erosion) and/or by the location of the erosional activity (surface or shoreline) or by the material being eroded (soil erosion).

Exchangeable sodium percentage (ESP): The percentage of the soil cation exchange capacity occupied by sodium ions. If this figure is 10 percent or higher, the soil is considered sodic.

Feasibility study: As applied to mining, the feasibility study follows discovery of the mineral and is done by the mining company. Its purpose is to analyze the rate of monetary return that

can be expected from the mine at a certain rate of production. Based on this study, the decision to develop the ore body may be made.

Flocculation: Aggregation of soil into lumps or masses.

Horizons, soil: Layers in the soil and overburden that differ in genetic characteristics, composition, or structure from adjacent layers. The various horizons in a soil are generally described by a diagram representing a vertical section of the soil called a profile. The horizons are designated as follows: A-horizon, topsoil; B-horizon, mineral soil; C-horizon, parent soil material, weathered or unweathered rock fragments, and minerals; D-horizon, a layer under the C-horizon which is unlike the parent material.

Hydraulic conductivity: A combined property of the conducting medium and the fluid that indicates the ability of the aquifer material to conduct water through it under a hydraulic gradient.

Inhibitory zones: Areas in the overburden that would prevent or limit plant growth if used as a plant-growing medium after mining.

Inoculation: Treating the soil by adding micro-organisms to it, or by adding soil or organic material containing desirable micro-organisms.

Interdisciplinary team (ID Team): As proposed by recent Forest Service regulations, the interdisciplinary team will be comprised of Forest Service personnel who collectively represent two or more areas of specialized technical knowledge about natural resources management applicable to the area being planned. The team will consider problems collectively, rather than separate concerns along disciplinary lines. This interaction will insure systematic, integrated consideration of physical, biological, economic, and other sciences.

Land-management plan: According to Forest Service regulations, each forest must have a forest plan, which outlines the most desired and alternative land uses for that site.

Leaching: To remove soluble constituents from a substance by the action of a percolating liquid.

Micro-organism: An animal or plant of microscopic size, especially a bacterium or protozoan.

Mining plan: Submitted by the mining operator, the mining plan outlines the steps the mining company will take to mine and rehabilitate the site. The mining plan is submitted prior to start-up of mining operations.

Monitoring: In regard to disturbances caused by mining, the site must be carefully observed following reclamation operations to insure that reclamation goals are being met. Monitoring usually involves observations over time.

Mulch: Any non-living material placed or left on or near the soil surface for the purpose of protecting it from erosion or protecting plants from heat, cold, or drought.

Mycorrhizal: Describes a symbiotic association of a fungus with the roots of certain plants.

Organic matter: Matter composed of once-living organisms; matter comprised of carbon compounds.

Overburden: Materials overlying a minable deposit up to, but not including, the topsoil.

Oxidation in soil: The combination of substances in the soil with oxygen. If the substance is a sulfide, this oxidation may result in an acidic condition.

pH: Symbol for the negative common logarithm of the hydrogen-ion concentration (acidity) of a solution. The pH scale runs from 0-14, with a pH of about 7 considered neutral. A pH number below 7 indicates acidity and a pH value above 7 indicates alkalinity or a base.

Performance bond: A bond of liability placed on a mining company. The bond specifies regulations for determining the acceptability of certain mining and reclamation activities.

Profile: A diagram representing a vertical section of the soils and overburden and showing the natural horizons in that material.

Sodic soil: A sodic soil occurs when exchangeable sodium ions are so concentrated in the soil that they may adversely affect plant growth. An ESP of 10 percent or higher, or an SAR of 10 or more may indicate a sodic soil.

Sodium adsorption ratio (SAR): A lab measurement of the ratio of soluble sodium to soluble calcium plus magnesium in soils. If the SAR is 10 or more, the soil may be sodic.

Soil: The loose, uncemented minerals and organic material on the immediate surface of the earth that serves as a natural medium for the growth of land plants; in this definition, soil only extends to the depth important for plant growth.

Soil survey: A general term for the systematic examination of soils in the field and in laboratories; their description and classification; the mapping of kinds of soil; their adaptability for various uses; their productivity.

Spoils: The overburden (soil and raw geologic materials) removed in gaining access to the desired mineral deposit.

Stockpiling: Storage of soils material for later use.

Storage areas: See Dumps.

Structure: Aggregates of primary particles of sand, silt, and clay into compound assemblies or clusters.

Texture: Relative proportion by weight of sand, silt, and clay.

Tillage: Any mechanical action that mixes or rips the soil.

Topsoil: The original or present dark-colored upper soil that ranges from a mere fraction of an inch to 2 or 3 ft thick on different kinds of soil. Most organic matter is concentrated in the topsoil. Usually refers to the "A" horizon of the soil profile.

Toxic soil: A soil containing concentrations of minerals so high as to be harmful to plants or animals.

Weathering: The process whereby larger particles of soils and overburden are reduced to finer particles by wind, water, temperature changes, and plant and bacteria action.

APPENDIX B

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USDA Forest Service.
1979. User guide to soils. USDA For. Serv. Gen. Tech. Rep. INT-68, 80 p. Intermt. For. and Range Exp. Stn., Ogden, Utah 84401.

Summarizes and discusses key questions and rules the soils scientist should consider when working in mining area reclamation. Topics include exploration and baseline data; soils and overburden analysis and sampling techniques; selecting storage areas; materials handling; spoils analysis; treating spoils problems; spoils surfacing; and monitoring and retreatment.

KEYWORDS: soils, revegetation, mining, mining area reclamation, mining area rehabilitation, land-management planning process.

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THE SEAM PROGRAM

The Surface Environment and Mining Program, known as SEAM, was established by the Forest Service to research, develop, and apply new technology to help maintain a quality environment while helping meet the Nation's mineral requirements. SEAM is a partnership of researchers, land managers, mining industries, universities, and political jurisdictions at all levels.

Although the SEAM Program was assigned to the Intermountain Station, some of its research projects were administered by the Rocky Mountain and Pacific Southwest Research Stations.

MINERAL USER GUIDES

Other User Guides for specialists involved in minerals activities are.

- User Guide to Vegetation, Gen. Tech. Rep., INT-64
- User Guide to Engineering, Gen. Tech. Rep., INT-70
- User Guide to Sociology and Economics, Gen. Tech. Rep., INT-73
- User Guide to Hydrology, Gen. Tech. Rep., INT-74
- User Guide for Wildlife (planned)
- User Guide for Visual Management (to be published as part of the National Forest Landscape Management Series)

To obtain copies of these guides, write: Intermountain Forest and Range Experiment Station, USDA Forest Service, 507 25th St., Ogden, UT 84401.